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An Analysis of the Learning Process in the Snail, *Physa gyrina* Say

BY

ELIZABETH LOCKWOOD THOMPSON

Contribution from the Zoological Laboratory of the University of Michigan No. 147

A dissertation submitted in partial fulfilment of the
requirements for the degree of Doctor of Philosophy in
the University of Michigan

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AN ANALYSIS OF THE LEARNING PROCESS IN THE SNAIL, *PHYSA GYRINA* SAY

INTRODUCTION

The experiments included in this paper were begun with the purpose of studying the ability of snails to discriminate between stimuli. To this end a method was adopted analogous to the salivary reflex method of Pawlow. Its use showed, among other things, a form of modifiability of behavior that could be interpreted only as learning—the capacity to form associations. The original plan to use this capacity as a basis for studies in discrimination was then changed. The discrimination experiments were deferred and the work was continued in order to determine if the snail, which can form associations, can also solve a simple labyrinth. The paper thus falls into two parts. Part one deals with modifiability as disclosed by the method of conditioned stimuli—with the power to form simple associations. Part two takes up the further question of the ability of the snail to solve a labyrinth and discusses the relation of this to the formation of simple associations. It is the purpose of the writer to return to the study of discrimination.

To Professor Jacob Reighard the author is indebted for suggesting the problem and for advice during the progress of the work; to Professor John F. Shepard she is indebted for numerous criticisms and suggestions.

I. MODIFIABILITY AS STUDIED BY A METHOD ANALOGOUS TO THE PAWLOW SALIVARY REFLEX METHOD

1. OUTLINE OF THE PROBLEM

The snail, *Physa gyrina* Say, like many other species, has the habit of crawling suspended from the surface film of the water. Its shell is then below and the ventral surfaces of the muscular foot and the head are exposed to view from above. The mouth may then often be seen to open and close many times in succession. Dawson (1911) found that when the region within a

millimeter or two of the mouth was touched with a bit of food or a clean glass rod, a chewing motion of the mouth parts began which "would continue for perhaps an hour or so, even if the animal were placed in fresh clean water." She found that the same stimuli applied to other parts of the animal produced no movements of the mouth parts. Familiarity with the mouth movements of this snail suggested that it might be a reflex of the same definite character as the salivary reflex made use of by Pawlow and his pupils in their studies of association and discrimination in the dog.

Pawlow (1904) opened the duct of the parotid gland of a dog to the outside by means of a fistula. He then measured the secretion and determined its quality (viscosity), when induced, first by the odor or sight of food unaccompanied by other experimental stimuli. Pawlow called this food stimulus an "unconditioned" stimulus. He then measured the secretion induced by food stimulation in the presence of an auxiliary (or secondary) stimulus such as sound or color. This he called a "conditioned" stimulus. After using the conditioned stimulus for a time, he omitted the primary stimulus (food) and found that the secretion was induced by the auxiliary stimulus, the tone or color, alone. He believed that he had shown conclusively that the animal had formed an association between the two stimuli since at first it had not reacted to the secondary stimulus, but after this stimulus had been used for a time in connection with the primary or food stimulus it had reacted to the secondary stimulus alone. Then by changing slightly the tone, color or other secondary stimulus used, he determined whether the animal reacted to this altered stimulus and to what extent. A change in the reaction was taken as evidence that the animal discriminated between the original and the altered stimulus. Thus power to discriminate between stimuli was tested.

Pawlow and his followers believed that the method could be used on only a limited number of mammals. "Its obvious limitation appears in the number of organisms with which it may be employed. Evidently it cannot be used for the study of animals which lack salivary glands, and even among those animals which do possess these glands there are many which surely would not lend themselves satisfactorily to the method. It seems therefore as if Pawlow's method were especially important in animal psy-

chology as a means to the intensive study of the mental life of a limited number of mammals." (Yerkes and Morgulis, 1909.) Theoretically, however, this method is applicable to any organism that responds to a stimulation by a specific, measurable reflex of muscles or glands. Such reflexes occur in many of the lower forms. The mouth movement of *Physa* is an example.

It was decided then to study:

(1.) The character of the response following a single application of a food stimulus to the mouth parts of the snail. Such a response consists of one or more reactions. A single complete movement—one reaction—may be compared to the secretion of a drop of saliva in the Pawlow experiments. A determination of the number of reactions per response was deemed comparable to Pawlow's measurements of the salivary secretion induced by food alone or resulting from an "unconditioned" stimulus.

(2.) Following this the application of two stimuli together, that is, food to the mouth parts and pressure at a fixed distance from the mouth, would, it was believed, correspond to Pawlow's "conditioned" stimulus. The number of reactions constituting each response would correspond to his measurements of saliva under such conditions.

(3.) It was then planned to apply the associated or auxiliary stimulus alone in the absence of food, in order to determine from the presence or absence of reactions, whether or not an association had been formed between the two stimuli.

2. MATERIAL AND METHODS

The snails* used in the experiments were collected in an oxbow pond that had been completely cut off from a small creek. Several hundred were brought into the laboratory and placed in large glass aquaria containing water plants such as *Elodea* and *Spirogyra*. An effort was made to have the environment in these aquaria as nearly like the natural habitat as possible. Besides the water plants upon which snails usually feed, fresh lettuce was placed in the aquaria. They ate this in comparatively large quantities, and seemed to prefer it to other plant food.

* The author is indebted to H. B. Baker and Harold Cummins for the identification of the snails used in the experiments.

When the tank containing recently captured snails was jarred or disturbed in any way, they would instantly expel the air from the lung, retract into their shells, and drop from the surface film upon which they were crawling, to the bottom of the tank. Many of them frequently remained motionless on the bottom for an hour or more before they again sought the surface and refilled their lungs. It became necessary therefore, to "tame" the snails which were to be used in the experiments, to so accustom them to handling that they would remain extended and retain the air in the lung while they were being worked upon.

About twenty specimens of approximately the same size were selected for the tests. These were placed in two bacteria dishes. In each dish was about a liter of water with water plants and as much lettuce as the snails would eat. The snails were taken in the hand at intervals and moved about under water. Each was held in the hand beneath the water until it emerged from the shell and suspended itself from the surface film. They gradually became accustomed to this handling to such an extent that they could be moved from dish to dish, at the will of the operator, without retracting or expelling the air from the lung.

These "tamed" snails were then divided into two groups. Each individual was numbered by means of white water-proof paint applied to the shell after it had been thoroughly dried. These groups were worked on alternate days. Each group was starved for a period of twenty-four hours before tests were made. The snails belonging to the group were thus believed to be in approximately the same state of hunger at the time of experimentation. After a group had been worked on it was allowed to feed for twenty-four hours and was again starved, before it was used. In this way an attempt was made to obtain physiological uniformity among the snails directly under observation. The physical conditions were also kept as uniform as possible. The whole series of daily experiments was carried on at approximately the same hour. Each snail in turn was placed in a clean dish of fresh, filtered tap water. The water was of the same depth and at the same (room) temperature as that in which the snails had been living and the lighting was at all times uniform with that to which they were accustomed. Each individual was put through a series of ten tests per day with one exception (check series, Table I, p. 6) and a separate record made of each.

3. THE RESPONSE TO THE FOOD STIMULUS

In order to utilize the snails it was necessary to know:

(1) Whether the mouth reactions occur only as the result of external stimulation, and

(2) Their constancy as to the number of reactions and the duration of the response following a single stimulus. Should they occur *regularly* as the result of external stimulation and *only then*, they must be regarded as "involuntary" responses or reflexes available for the purpose of the experiments. Upon the constancy and duration of the response depends its value for quantitative uses.

A. *The response to the food stimulus a reflex.*—It was found by observation not only that the mouth movements of *Physa* were induced by food and mechanical stimulation of the mouth region, but that they also sometimes occurred when no such stimuli could be detected. Such apparently voluntary movements might be due to the stimuli from microscopic particles in the water. A check series of experiments in filtered *water was deemed necessary in order to determine whether or not the mouth reactions might normally occur without external stimulation and if so under what conditions and with what frequency. In these tests each snail, under the controlled conditions just mentioned, was in turn held in the hand of the operator until it suspended itself from the surface film. It was then permitted to move about, and was touched only when necessary to keep it from crawling down the sides of the dish. At such times it was pushed gently toward the center of the tank with a sterile glass rod. Each animal was thus kept crawling on the surface film for an average period of forty-five minutes under constant observation and a record was made of each mouth reaction. It was found to be impossible to keep the snail absolutely free from all chance stimulation of the mouth. It has been shown that the animal uses the same method of locomotion in crawling on the surface film that it does in moving over any substratum, that is, it crawls along a mucous path which it secretes as it moves and which remains behind it on the surface of the water. (Parker, 1912), (Dawson, 1911). The mucus thus left on the surface may reach the mouth of the snail as it moves about. In

*A Berkefeldt filter was used.

several instances this mucus was observed to touch the mouth parts and such contact was followed by reactions. These are noted in the following table. Stimulation of this sort is the probable cause of all other reactions that occur in the test series.

TABLE I

Showing the number of reactions of the mouth of six individuals of *Physa gyrina* Say, kept under observation in filtered tap water for 32.75 hours, when not stimulated by the application of food to the mouth region. The snails had been without food for 24 hours preceding the tests. They were divided into two groups of three each and tested on alternating days.

Snail No.	No. of days tested	Period of observation in minutes each day	No. of mouth reactions, no visible stimulus	No. of mouth reactions, mucous stimulation
18	1	60	0	0
	2	45	0	0
	3	60	0	0
	4	60	0	0
	5	60	0	0
	6	60	0	0
19	1	60	0	0
	2	45	2	14
	3	60	0	5
	4	60	1	0
	5	60	0	0
	6	60	0	0
20	1	60	0	0
	2	45	0	0
	*3	60	0	0
	4	60	0	0
	5	60	0	0
21	1	30	0	0
	2	60	0	0
	3	60	0	0
	4	60	0	0
	5	60	0	0
	6	60	0	0
22	1	30	0	0
	2	60	0	0
	3	60	0	0
	4	60	0	0
	5	60	0	0
	6	60	0	0
23	1	30	7	0
	2	60	4	0
	3	60	0	2
	4	60	3	0
	5	60	0	0
	6	60	0	0

* Indicates that an egg mass had been deposited within the 24 hours preceding the test.

TABLE I—(Continued)

Total time of observation.....	32.75 hrs.
Total number of reactions.....	38
Total number of reactions, no visible cause.....	17 (44.73%)
Total number of reactions, mucous stimulation.....	21 (55.26%)
Average number of reactions per hour.....	1.16
Average number of reactions, no visible cause, per hour.....	0.51

This table shows that when six snails were kept under observation for nearly thirty-three hours (about five and a half hours each) in filtered tap water only 38 mouth reactions were observed, an average of 1.16 per hour. If we allow for each reaction 1.25 seconds (Table II, p. 8) the duration of the 38 reactions is 47.50 seconds. Of the 38 reactions 21 or 55.26% were observed to be due to mucous stimulation and the remainder were probably due to the same cause. Owing to the fact that the mucus is colorless, and as it occurs on the surface of the water, transparent, it is exceedingly difficult to determine its presence at all times. Any attempt to bring it into view by the addition of pigment such as powdered carmine would only serve to make it more effective as a stimulus. The reactions which did occur can then be accounted for. The mouth reactions of *Physa* may then be regarded as a true reflex, an "unlearned response" (Watson, 1914), which occurs normally as the result of external stimulation of the mouth or the region immediately surrounding it. For experimental purposes we may say that the reaction occurs only as the result of external stimulation. If now, the snail were placed in water freed from microscopic particles by filtration and the mouth reactions were practically always induced by bringing food directly into contact with the mouth, the reactions must be regarded as reflexes, that is, involuntary. Such a series of reactions then might be interpreted as an "unconditioned reflex" (Pawlow, 1904). The number of reactions and the duration of the series should then prove an available substitute for the measurements of saliva in inquiries into the behavior of a group of animals widely separated from mammals.

B. Number and duration of reactions in the normal food-stimulus response.—The snails that were used in all of the remaining tests had been fed upon lettuce while in the laboratory; for this reason lettuce was used as a food stimulus in all the experiments. A small piece taken from a fresh leaf was applied to the normally inactive mouth of the snail by means of forceps

and immediately withdrawn. This stimulus served to start the movements of the mouth parts, and an exact record of the number of reactions thus induced was kept for each individual. Each complete opening and closing movement is spoken of as a *reaction*. The number of reactions (whether one or several) induced by a single stimulation of the mouth parts is termed a *response*. During work a record was also made of the length of time that the reactions persisted; that is, the duration of the response (Table II).

TABLE II

Showing the number of reactions of the mouth of two individuals of *Physa gyrina* Say, resulting from a single application of food to the mouth. The tests were made in filtered water on alternating days. The snails had been starved for 24 hours preceding the tests.

SNAIL No. 4				
No. of days tested	No. for "food stimulus" series	No. of trial for day	No. of reactions per response	Duration of response in sec.
1	1	1	1	1
	2	2	0	0
	3	3	1	1
	4	4	6	10
	5-10	5-10	0	0
		10	8	
Totals.....				
Av. per response.....			2.66	
2	11	1	1	1
	12	2	6	10
	13	3	38	50
	14	4	*	0
	15	5	1	1
	16	6	1	1
	17	7	3	5
	18	8	1	1
	19-20	9-10	0	0
Totals.....		10	51	
Av. per response.....			7.28	
3	21	1	0	0
	22	2	1	1
	23	3	1	1
	24	4	1	1
	25	5	1	1
	26	6	1	1
	27	7	2	3
	28	8	0	0
	29	9	1	1
	30	10	0	0
		10	8	
Totals.....				
Av. per response.....			1.14	

* Cases in which lack of response was due to known mechanical disturbance.

TABLE II—(Continued)

SNAIL NO. 4—(Continued)

No. of days tested	No. for "food stimulus" series	No. of trial for day	No. of reactions per response	Duration of response in sec.
4	31	1	3	4
	32	2	2	2
	33	3	1	1
	34	4	1	1
	35	5	1	1
	36	6	2	2
	37	7	1	1
	38	8	2	2
	39-40	9-10	0	0
Totals.....		10	13	
Av. per response.....			1.62	
5	41	1	11	15
	42	2	6	8
	43	3	0	0
	44	4	3	3
	45	5	1	1
	46	6	0	0
	47-50	7-10	*	0
Totals.....		10	21	
Av. per response.....			5.25	

Total number of trials.....	50
Total number of stimuli followed by response.....	29
Per cent of stimuli followed by response.....	58%
Total number of reactions.....	101
Average number of reactions per trial.....	2.02
Average number of reactions in only those trials in which response occurred.....	3.48
Total time of reactions.....	2.18 min.
Average time per reaction.....	1.29 sec.
Average number of reactions per minute.....	46.51

* Cases in which lack of response was due to known mechanical disturbance.

TABLE II—(Continued)

SNAIL No. 5

No. of days tested	No. for "food stimulus" series	No. of trial for day	No. of reactions per response	Duration of response in sec.
1	1	1	24	30
	2-4	2-4	0	0
	5-10	5-10	*	0
Totals.....		10	24	
Av. per response.....			24	
2	11	1	5	10
	12	2	1	1
	13	3	*	0
	14	4	0	0
	15	5	1	1
	16	6	1	1
	17	7	2	3
	18	8	1	1
	19-20	9-10	*	0
Totals.....		10	11	
Av. per response.....			1.83	
3	21	1	1	1
	22	2	1	1
	23	3	1	1
	24	4	2	3
	25	5	2	3
	26	6	1	1
	27-30	7-10	*	0
Totals.....		10	8	
Av. per response.....			1.33	
4	31	1	3	3
	32	2	4	5
	33	3	4	5
	34	4	2	2
	35	5	1	1
	36	6	1	1
	37	7	1	1
	38	8	1	1
	39	9	4	4
	40	10	1	1
Totals.....		10	22	
Av. per response.....			2.2	
5	41	1	19	22
	42	2	20	22
	43	3	5	6
	44	4	10	12
	45	5	4	8
	46	6	6	5
	47	7	1	1
	48	8	0	0
	49	9	3	4
	50	10	6	8
Totals.....		10	74	
Av. per response.....			8.22	

* Cases in which lack of response was due to known mechanical disturbance.

TABLE II—(Continued)

Total number of trials.....	50
Total number of stimuli followed by response.....	32
Per cent of stimuli followed by response.....	64%
Total number of reactions.....	139
Average number of reactions per trial.....	2.78
Average number of reactions in only those trials in which response occurred.....	4.35
Total time of reactions.....	2.81 min.
Average time per reaction.....	1.21 sec.
Average number of reactions per minute.....	45.9
Summary, Snails 4 and 5:	
Total number of stimuli (trials).....	100
Total number of stimuli followed by response.....	61
Per cent of stimuli followed by response.....	61%

Table II shows that when a food stimulus is applied to the mouth region of *Physa gyrina* Say, response occurs in 61% of 100 trials with two snails. The individual records show that the number of reactions making up the response varies from 1 to 38. The first 30 trials of the series of 50 trials for Snail 4 shows 67 reactions, while the following 20 trials give 34 reactions with an average of 2.83' reactions per response. In the case of Snail 5 the corresponding numbers are 43 and 96 reactions with an average per response of 3.3 and 5.05. This indicates in the case of Snail 5 a tendency to recover during the second part of the series from the inhibiting effect of the manipulation (adaptation). In Snail 4 the recovery may be delayed beyond the limits of the series. The series is in both cases too short to afford anything more than a suggestion as to the occurrence of adaptation. The absence of reaction in certain trials and the wide variation in their number in those trials in which they occur and in the differences between individual snails, are brought out in the summary (p. 31) and are discussed later. The average number of reactions per response furnishes a means of comparison of the results here obtained with those recorded in the part of this paper which deals with the simultaneous use of two stimuli.

4. RESPONSE TO THE CONDITIONED FOOD STIMULUS: SIMULTANEOUS APPLICATION OF FOOD AND PRESSURE

There are then determined the number of reactions of the mouth parts induced by a single definite stimulation and constituting a single response and the duration of the response and of the single reaction. The stimulus according to Pawlow's terminology would be "unconditioned" or primary. An attempt was next

made to use a "conditioned" or double stimulus by the simultaneous application of pressure and food.

A. *Special apparatus and methods.*—This required the construction of a special apparatus which would make possible the application of a uniform pressure at a fixed distance from the food stimulus when the latter was applied to the mouth of the snail. Out of the several appliances tried, the one here pictured (fig. 1, Plate I) gave the best results.

(A) was a wire nail which served as a handle. A small strip of sheet metal (B) 5 mm. in width, and bent in the form of a square cornered U, was soldered to the end of A. B contained two smooth-edged holes, one directly above the other and both as large as would permit the free movement through them of a smooth steel rod (C) which was made from a No. 5 sewing needle. C was kept from dropping through the holes, by a fine wire (D) which was passed through the eye of the needle. To the lower end of the rod C was soldered a U-shaped piece made of No. 30 platinum wire. One limb of the U (E) 16 mm. in length, ended in a small hook. The other limb (F) 18 mm. in length, ended in a three-pronged, dull-pointed platinum fork 3 mm. wide and turned at right angles to the plane of the U-shaped piece. A was held in the hand of the operator and the fork on the lower end of F was allowed to rest on the exposed ventral surface of the snail. At the same time food (a small piece of lettuce rolled between the fingers to form an inverted cone) suspended from the hook at the lower end of E was applied to the mouth of the snail. The free movement of the lower part of the apparatus permitted by the smooth-edged holes in B, made it possible for the operator to manipulate the apparatus in such a way that it remained practically stationary upon the surface of the snail during the period of stimulation in spite of the constant motion of the animal.

B. *Experiments which show lack of response of untrained snails to pressure alone.*—Before using the apparatus in experiments with the conditioned stimulus, a series of twenty trials was made on each of six snails in order to learn whether the application to the foot of the pressure fork alone induced response. The snails were starved for twenty-four hours previous to the experiments and each was tested in filtered tap water. The above

described apparatus was applied without food to the upturned ventral surface of the foot. It was placed upon the animal in such a way that the food hook was just above the mouth. Pressure was thus applied to the same part of the foot that would receive it if the double stimuli, food and pressure, were being applied together. In the total of 120 trials 4 responses occurred (3.33%) and these were probably due to mucous stimulation. Pressure alone, as applied with the apparatus used is followed by response in so small a percentage of the trials that its occurrence does not vitiate the experiments which follow.

C. *Experiments to determine response to the conditioned food stimulus: first food and pressure series.*—By means of the food-pressure apparatus food and uniform pressure were next applied simultaneously in a long series of trials. Both stimuli were immediately withdrawn and the number of reactions of the mouth counted and recorded as before. Table III shows the record obtained in this attempt to form an association between two dissimilar stimuli applied simultaneously.

TABLE III

Showing the number of reactions of the mouths of two individuals of *Physa gyrina* Say, resulting from the simultaneous application of two dissimilar stimuli, food and pressure. The tests were made in filtered tap water on alternating days. The snails had been starved for 24 hours preceding the tests.

SNAIL NO. 4				
No. of days tested	No. for "food and pressure" stimulus series	No. of trial for day	No. of reactions per response	Duration of response in sec.
6	1-10	1-10	0	0
7	11-20	1-10	0	0
8	21-30	1-10	0	0
9	31-40	1-10	0	0
10	41-50	1-10	0	0
11	51-60	1-10	0	0
Totals.....		60	0	
12	61	1	4	5
	62	2	1	1
	63	3	2	2
	64-70	4-10	0	0
Totals.....		10	7	
Av. per response.....			2.33	

TABLE III—(Continued)

SNAIL NO. 4—(Continued)

No. of days tested	No. for "food and pressure" stimulus series	No. of trial for day	No. of reactions per response	Duration of response in sec.
13	71-80	1-10	0	0
14	81	1	0	0
	82	2	1	1
	83	3	8	10
	84-90	4-10	0	0
Totals.....		10	9	
Av. per response.....			4.5	
15	91	1	1	1
	92	2	1	1
	93	3	0	0
	94	4	2	2
	95-100	5-10	0	0
Totals.....		10	4	
Av. per response.....			1.33	
16	101-110	1-10	0	0
17	111	1	16	18
	112	2	6	8
	113	3	0	0
	114	4	1	1
	115	5	1	1
	116	6	0	0
	117	7	1	1
	118	8	1	1
	119	9	2	2
	120	10	0	0
Totals.....		10	28	
Av. per response.....			4.0	
18	121	1	1	1
	122	2	0	0
	123	3	2	2
	124	4	2	2
	125	5	5	6
	126	6	2	2
	127	7	1	1
	128	8	1	1
	129-130	9-10	0	0
Totals.....		10	14	
Av. per response.....			2.0	
19	131	1	25	27
	132	2	6	8
	133	3	30	33
	134	4	4	5
	135	5	7	8
	136-140	6-10	0	0
Totals.....		10	72	
Av. per response.....			14.4	

TABLE III—(Continued)

SNAIL NO. 4—(Continued)

No. of days tested	No. for "food and pressure" stimulus series	No. of trial for day	No. of reactions per response	Duration of response in sec.
20	141	1	19	22
	142	2	30	35
	143	3	8	9
	144	4	10	12
	145	5	3	3
	146	6	0	0
	147	7	1	1
	148	8	*	0
	149-150	9-10	0	0
Totals.....		10	71	
Av. per response.....			11.83	
21	151	1	8	9
	152	2	8	10
	153	3	2	2
	154	4	3	4
	155	5	*	0
	156	6	2	2
	157	7	0	0
	158	8	9	10
	159-160	9-10	0	0
Totals.....		10	34	
Av. per response.....			5.66	
22	161	1	1	1
	162	2	0	0
	163	3	1	1
	164	4	1	1
	165	5	1	1
	166	6	1	1
	167-170	7-10	0	0
Totals.....		10	5	
Av. per response.....			1.0	
23	171	1	10	13
	172	2	12	16
	173	3	2	2
	174	4	1	1
	175	5	1	1
	176	6	4	5
	177	7	1	1
	178	8	9	12
	179	9	3	4
	180	10	1	1
Totals.....		10	44	
Av. per response.....			4.4	

* Cases in which lack of response was due to known mechanical disturbance.

TABLE III—(Continued)

SNAIL No. 4—(Continued)

No. of days tested	No. for "food and pressure" stimulus series	No. of trial for day	No. of reactions per response	Duration of response in sec.
24	181-190	1-10	0	0
25	191	1	4	5
	192	2	1	1
	193	3	4	5
	194	4	1	1
	195	5	1	1
	196	6	4	5
	197	7	1	1
	198-200	8-10	0	0
Totals.....		10	16	
Av. per response.....			2.28	
26	201	1	2	2
	202	2	3	4
	203	3	6	8
	204	4	1	1
	205	5	1	1
	206	6	2	2
	207	7	2	2
	208	8	3	4
	209	9	2	2
	210	10	2	2
Totals.....		10	24	
Av. per response.....			2.4	
27	211	1	3	4
	212	2	4	5
	213	3	5	6
	214	4	0	0
	215	5	1	1
	216-220	6-10	0	0
Totals.....		10	13	
Av. per response.....			3.25	
28	221	1	4	5
	222	2	1	1
	223	3	2	2
	224	4	1	1
	225	5	1	1
	226	6	4	5
	227	7	1	1
	228	8	1	1
	229	9	2	2
	230	10	1	1
Totals.....		10	18	
Av. per response.....			1.8	

TABLE III—(Continued)

SNAIL No. 4—(Continued)

No. for days tested	No. for "food and pressure stimulus" series	No. of trials for day	No. of reactions per response	Duration of response in sec.
29	231	1	1	1
	232	2	1	1
	233	3	1	1
	234	4	1	1
	235	5	1	1
	236-240	6-10	0	0
Totals.....		10	5	
Av. per response.....			1.0	
30	241	1	10	12
	242	2	1	1
	243	3	1	1
	244	4	1	1
	245	5	1	1
	246	6	1	1
247-250		7-10	0	0
Totals.....		10	15	
Av. per response.....			2.5	
31	251	1	4	5
	252	2	5	6
	253	3	5	6
Totals.....		3	14	
Av. per response.....			4.66	
Total number of trials.....				253
Total number of stimuli followed by response.....				99
Per cent of stimuli followed by response.....				35%
Total number of reactions.....				393
Average number of reactions per trial.....				1.55
Average number of reactions in only those trials in which response occurred.....				3.96
Total time of reactions.....				7.58 min.
Average time per reaction.....				1.15 sec.
Average number of reactions per minute.....				51.84

TABLE III—(Continued)

SNAIL No. 5					
	No. of days tested	No. for "food and pressure" stimulus series	No. of trials for day	No. of reactions per response	Duration of response in sec.
	6	1-10	1-10	0	0
	7	11-20	1-10	0	0
	8	21-30	1-10	0	0
	9	31-40	1-10	0	0
	10	41-50	1-10	0	0
	11	51-60	1-10	0	0
	12	61-70	1-10	0	0
	13	71-80	1-10	0	0
Totals...			80	0	0
Totals.....	14	81-90	10	14	16
Av. per response..				14.0	
Totals.....	15	91-100	10	0	0
Totals.....	16	101-110	10	0	0
Totals.....	17	111-120	10	24	28
Av. per response..				4.8	
Totals.....	18	121-130	10	11	12
Av. per response..				1.83	
Totals.....	19	131-140	10	74	85
Av. per response..				9.25	
Totals.....	20	141-150	10	23	27
Av. per response..				2.87	
Totals.....	21	151-160	10	0	0
Totals.....	22	161-170	10	0	0
Totals.....	23	171-180	10	13	16
Av. per response..				3.25	
Totals.....	24	181-190	10	3	3
Av. per response..				1.0	
Totals.....	25	191-200	10	13	15
Av. per response..				3.25	
Totals.....	26	201-210	10	17	19
Av. per response..				1.7	
Totals.....	27	211-220	10	0	0
Totals.....	28	221-230	10	0	0
Totals.....	29	231-240	10	5	5
Av. per response..				1.25	
Totals.....	30	241-250	10	28	34
Av. per response..				3.11	

TABLE III—(Continued)

SNAIL No. 5—(Continued)

Total number of trials.....	250
Total number of stimuli followed by response.....	62
Per cent of stimuli followed by response.....	24%
Total number of reactions.....	225
Average number of reactions per trial.....	0.9
Average number of reactions in only those trials in which response occurred.....	3.62
Total time of reactions.....	4.33 min
Average time per reaction.....	1.11 sec.
Average number of reactions per minute.....	51.92

Summary Snails 4 and 5:

Total number of stimuli (trials).....	503
Total number of stimuli followed by response.....	161
Per cent of stimuli followed by response.....	32%

TABLE III-A

Showing the distribution of responses of each 10 trials of the 250 trials shown in Table III.

SNAIL No. 4

Trials no.	No. of responses	Total no. of reactions	Total duration in sec. of responses per 10 trials	Average duration of reactions
1- 60	0	0	0	0
61- 70	3	7	8	1.14
71- 80	0	0	0	0
81- 90	2	9	11	1.22
91-100	3	4	4	1.0
101-110	0	0	0	0
111-120	7	28	32	1.14
121-130	7	14	15	1.07
131-140	5	72	81	1.12
141-150	6	71	82	1.15
151-160	6	34	39	1.14
161-170	5	5	5	1.0
171-180	10	44	56	1.27
181-190	0	0	0	0
191-200	7	16	19	1.18
201-210	10	24	28	1.16
211-220	4	13	16	1.23
221-230	10	18	20	1.11
231-240	5	5	5	1.0
241-250	6	15	17	1.13
251-253	3	14	17	1.21

SNAIL No. 5

1- 80	0	0	0	0
81- 90	1	14	16	1.14
91-100	0	0	0	0
101-110	0	0	0	0
111-120	5	24	28	1.16
121-130	6	11	12	1.09
131-140	8	74	85	1.14

TABLE III-A—(Continued)

SNAIL NO. 5—(Continued)				
Trials no.	No. of responses	Total no. of reactions	Total duration in sec. of responses per 10 trials	Average duration of reactions
141-150	8	23	27	1.13
151-160	0	0	0	0
161-170	0	0	0	0
171-180	4	13	16	1.23
181-190	3	3	3	1.0
191-200	4	13	15	1.15
201-210	10	17	19	1.11
211-220	0	0	0	0
221-230	0	0	0	0
231-240	4	5	5	1.0
241-250	9	28	34	1.21
SNAIL NO. 6				
1-110	0	0	0	0
111-120	1	6	7	1.16
121-130	0	0	0	0
131-140	2	9	11	1.22
141-150	2	2	2	1.0
151-160	0	0	0	0
161-170	0	0	0	0
171-180	0	0	0	0
181-190	3	3	3	1.0
191-200	2	2	2	1.0
201-210	5	6	6	1.0
211-220	0	0	0	0
221-230	5	5	5	1.0
231-240	4	7	7	1.0
241-250	9	25	29	1.16
SNAIL NO. 7				
1- 50	0	0	0	0
51- 60	1	1	1	1.0
61- 70	1	11	13	1.18
71- 80	0	0	0	0
81- 90	2	2	2	1.0
91-100	3	10	13	1.3
101-110	0	0	0	0
111-120	4	27	31	1.11
121-130	3	6	7	1.16
131-140	5	32	41	1.21
141-150	3	38	44	1.15
151-160	3	4	4	1.0
161-170	4	11	13	1.18
171-180	4	46	55	1.19
181-190	4	4	4	1.0
191-200	10	35	44	1.25
201-210	8	11	12	1.09
211-220	10	13	13	1.0
221-230	4	7	8	1.14
231-240	5	29	33	1.13
241-250	8	50	56	1.12

TABLE III-A--(Continued)

SNAIL No. 8				
Trials no.	No. of responses	Total no. of reactions	Total duration in sec. of responses per 10 trials	Average duration of reactions
1- 80	0	0	0	0
81- 90	1	1	1	1.0
91-100	0	0	0	0
101-110	0	0	0	0
111-120	1	2	3	1.5
121-130	2	2	2	1.0
131-140	1	2	2	1.0
141-150	2	3	3	1.0
151-160	5	9	9	1.0
161-170	0	0	0	0
171-180	3	4	4	1.0
181-190	0	0	0	0
191-200	4	4	4	1.0
201-210	4	4	4	1.0
211-220	0	0	0	0
221-230	9	10	10	1.0
231-240	10	21	24	1.14
241-250	8	9	9	1.0
251-253	3	13	15	1.15
SNAIL No. 14				
1- 60	0	0	0	0
61- 70	3	7	8	1.14
71- 80	0	0	0	0
81- 90	1	4	5	1.25
91-100	2	3	3	1.0
101-110	2	3	4	1.33
111-120	0	0	0	0
121-130	3	13	16	1.23
131-140	5	29	35	1.2
141-150	3	4	4	1.0
151-160	2	5	6	1.2
161-170	3	8	9	1.12
171-180	0	0	0	0
181-190	1	1	1	1.0
191-200	0	0	0	0
201-210	7	25	31	1.24
211-220	6	32	38	1.18
221-230	0	0	0	0
231-240	4	31	37	1.12
241-250	5	17	19	1.11

TABLE III-B

Showing the distribution of responses of each 50 trials of the 250 trials of the "food-pressure" stimulus series.

SNAIL No. 4				
Trials no.	No. of responses	Total no. of reactions	Total duration in sec. of responses per 50 trials	Average duration of reactions
1- 50	0	0	0	0
51-100	8	20	23	1.13
101-150	25	185	210	1.13
151-200	28	99	119	1.2
201-250	35	75	86	1.14
SNAIL No. 5				
1- 50	0	0	0	0
51-100	1	14	16	1.14
101-150	27	132	152	1.15
151-200	11	29	34	1.17
201-250	23	50	58	1.16
SNAIL No. 6				
1- 50	0	0	0	0
51-100	0	0	0	0
101-150	5	17	20	1.17
151-200	5	5	5	1.0
201-250	23	43	47	1.09
SNAIL No. 7				
1- 50	0	0	0	0
51-100	7	24	29	1.2
101-150	15	103	123	1.19
151-200	25	100	120	1.2
201-250	35	110	122	1.1
SNAIL No. 8				
1- 50	0	0	0	0
51-100	1	1	1	1.0
101-150	6	9	10	1.11
151-200	12	17	17	1.0
201-250	31	44	47	1.06
SNAIL No. 14				
1- 50	0	0	0	0
51-100	6	14	16	1.14
101-150	13	49	59	1.2
151-200	6	14	16	1.14
201-250	22	105	125	1.19

From Table III it appears that when two stimuli were applied simultaneously, food to the mouth and pressure to the foot, there was at first an inhibitory effect upon the reflex. This is shown in the first 60 to 80 trials in which no reaction followed the application of the double stimulus. When this table is

compared with Table II it is seen that a slight inhibition continued throughout this series of tests as indicated in the average number of responses per 50 trials (Table III-B) and the per cent of stimuli followed by response (Tables III and VI). The average number of reactions per response was also less than in the normal food series. For the food-pressure response the average number of reactions in the numerical order of the six snails was 3.96, 3.62, 1.96, 4.1, 1.58, 3.78, or a mean for all six snails of 3.18. The corresponding values for the normal food response (Table II) are 3.48, 4.35, 6.5, 6.5, 3.4, 10.93, with a mean value of 5.85 for the six snails. Only in the case of Snail No. 4 is there a greater average number of reactions per response to the "conditioned" stimulus than to the "unconditioned." Table III shows further that the average duration of the reactions in the food pressure response is less than that of the normal food response. Expressed in the number of reactions per minute the values are 51.84, 51.92, 65.45, 51.72, 56.7, 50.84, with a mean of 54.74. The corresponding values for the normal food response are 46.51, 45.9, 46.15, 46.51, 44.44, 48.00 with a mean of 46.25. Under food-pressure stimulation the reactions thus occur at the rate of 8.49 more per minute than under the normal food stimulus. Along with the reduction in the number of reactions there is in the food-pressure response an acceleration of the individual reaction as compared with that of the normal food response.

The distribution of the reactions over the series of 250 trials is shown for the six snails in Tables III-A and III-B and is represented in graphs (figs. 2-13, Plates II-III). Table III-A and figs. 2-7 (Plate II) show the great fluctuation in the number of reactions per response. This fluctuation causes the reaction curve to vary from the response curve although the two are in general similar in direction. The response curve shows a somewhat more uniform rise than the reaction curve. A general fact to be noted is the relative uniformity in the average duration of the individual reactions throughout the series. The method of timing the response duration by means of the stop watch is necessarily inaccurate, especially with values which, as in this case, are frequently in the neighborhood of a second. If a more accurate method were available greater uniformity might be expected. With the method employed it is noteworthy that the agreement is so close.

The food-pressure series thus shows the following characteristics: (1) An absence of reaction at the beginning, (2) a similarity in the reaction and response curves, (3) in general, a gradual rise of the response curve, (4) a less average number of responses per 50 trials and a less average number of reactions per response as compared with the normal food series, with the exception of Snail No. 4, (5) an increase in the number of reactions per minute, i. e. an acceleration of the individual response, (6) a fairly constant reaction duration. This is characteristic of all the series.

D. *Experiments with pressure alone on trained snails: association.*—The third part of the problem called for the application of the secondary stimulus alone. Any mouth reactions which might follow (beyond those attributed to chance stimulation of the mouth), would according to the Pawlow theory be evidence that an association had been formed between the essential, primary or “unconditioned” stimulus and the secondary—or in this case, between food and pressure. The series of tests was carried on in exactly the same manner as the experiments just described. The same apparatus was used but no food was placed upon the food hook. Since the food hook was shorter than the pressure fork (fig. 1, Plate I) it did not touch the mouth, which therefore received neither food nor mechanical stimulation. The pressure fork was applied to the usual place on the ventral surface of the snail. The following table (IV) shows the results obtained.

TABLE IV

Showing the number of reactions of the mouth of two individuals of *Physa gyrina* Say, resulting from the application of pressure alone as a stimulus, after an attempt had been made to establish an association between the two stimuli, food and pressure (Table III). The tests were made in filtered tap water on alternating days. The snails had been starved for 24 hours preceding the tests.

SNAIL No. 4				
No. of days tested	No. for "pressure" stimulus series	No. of trial for day	No. of reactions per response	Duration of response in sec.
31	1	*4	3	4
	2	5	1	1
	3	6	1	1
	4	7	1	1
	5	8	1	1
	6	9	1	1
	7	10	0	0
Totals.....		7	8	
Av. per response.....			1.33	
32	8	1	1	1
	9	2	1	1
	10-17	3-10	0	0
Totals.....		10	2	
Av. per response.....			1.0	
33	18-27	1-10	0	0
34	28-37	1-10	0	0
Total number of trials (last 20 trials omitted).....				17
Total number of stimuli followed by response.....				8
Per cent of stimuli followed by response.....				47%
Total number of reactions.....				10
Average number of reactions per trial.....				0.58
Average number of reactions in only those trials in which response occurred.....				1.25
Total time of reactions in seconds.....				11
Average time per reaction in seconds.....				1.1
Average number of reactions per minute (estimated).....				54.54

SNAIL No. 5

No. of days tested	No. for "pressure" stimulus series	No. of trial for day	No. of reactions per response	Duration of response in sec.
31	1	1	11	14
	2	2	1	1
	3	3	1	1
	4	4	12	14
	5	5	1	1
	6	6	5	6
	7	7	3	4
	8-10	8-10	0	0
Totals.....		10	34	
Av. per response.....			4.85	

* For trials 1-3 on the 31st day see Table III (31st day).

TABLE IV—(Continued)

SNAIL NO. 5—(Continued)

No. of days tested	No. for "pressure" stimulus series	No. of trials for day	No. of reactions per response	Duration of response in sec.
32	11	1	1	1
	12	2	1	1
	13-20	3-10	0	0
Totals.....		10	2	
Av. per response.....			1.0	
33	21-30	1-10	0	0
34	31-40	1-10	0	0
Total number of trials (last 20 trials omitted).....				20
Total number of stimuli followed by response.....				9
Per cent of stimuli followed by response.....				45%
Total number of reactions.....				36
Average number of reactions per trial.....				1.8
Average number of reactions in only those trials in which response occurred.....				4
Total time of reactions in seconds.....				43
Average time per reaction in seconds.....				1.19
Average number of reactions per minute (estimated).....				50.42
Summary Snails 4 and 5.				
Total number of stimuli (trials).....				37
Total number of stimuli followed by response.....				17
Per cent of stimuli followed by response.....				45.9%

Table IV shows that when the secondary stimulus, pressure, alone was applied to the mouth of *Physa*, the mouth reacted in 17 out of 37 trials with two individuals, or in 45.9% of the trials. No mucous stimulation was observed. The average number of reactions per response was for Snail 4, 1.25 and for Snail 5, 4.0 (Table IV). Snails Nos. 6, 7, 8, 14 were given a similar series of tests which are not here tabulated in detail but are summarized in Table V-C. These showed the following average number of reactions per response 4.92, 6.09, 8.0, 3.8. The mean for the six snails is 4.67. The mean for the normal food series is for six snails 5.86. For the food-pressure series it is 3.18. The average duration of reactions for the pressure response of trained snails is less than for the normal food response. The average rate per minute is 53.9, 7.65 reactions per minute in excess of that of the normal food response.

These trials followed 48 hours after the completion of the

training in the food-pressure series. In the case of Snail 4, response followed the first nine trials. The last two of these are separated by an interval of 48 hours from the first seven. The effect of training thus persisted for 96 hours. Similar results were obtained from Snails 5, 6, 7, 8 and 14.

Immediately following the mouth response to pressure of trained Snail No. 4 (Table IV) seven successive applications of pressure gave no response. Similar results were obtained with the other five snails.

Snails which before training gave no response to pressure, gave, following training, a response consisting of a series of mouth reactions. This response is given on the first trial and continues to be given in trials extending over a period of 96 hours. It then suddenly ceases. There is no response of the mouth to subsequent stimulation of the foot by pressure.

E. *Experiments to determine the effect of training on food-pressure response: second food-pressure series.*—It was believed that another series of tests on the same snails, reintroducing the same "conditioned" stimulus, would be of interest in showing the ease or difficulty in re-establishing the reflex. As noted in Table IV, the snails were tested on two experimental days after pressure alone had failed to be effective as a stimulus. Allowing for the alternation of experimental days, made necessary by the twenty-four hours of starving previous to experimentation, the second series of tests using food and pressure as a stimulus was started approximately 120 hours after the disappearance of reaction upon the application of pressure as a stimulus. Fifty tests were given and the results appear in Tables V and VI-D.

TABLE V

Showing the number of reactions of the mouths of two individuals of *Physa gyrina* Say, resulting from the simultaneous application of food and pressure after the complete disappearance (Table IV) of the effect of the association established between these two stimuli (Table III). The tests were made in filtered water on alternating days. The snails had been starved for 24 hours preceding the tests.

SNAIL NO. 4

No. of days tested	No. for "food and pressure" stimulus, second series	No. of trial for day	No. of reactions per response	Duration of response in sec.
35	1	1	11	13
	2	2	10	12
	3	3	2	3
	4-10	4-10	0	0
Totals.....		10	23	
Av. per response.....			7.66	
36	11	1	3	5
	12	2	3	5
	13	3	7	10
	14	4	6	8
	15	5	3	5
	16	6	2	3
	17	7	1	1
	18	8	2	3
	19	9	2	3
	20	10	2	3
Totals.....		10	31	
Av. per response.....			3.1	
37	21	1	8	11
	22	2	6	8
	23	3	3	5
	24	4	8	10
	25	5	2	4
	26	6	5	8
	27	7	6	9
	28	8	7	10
	29	9	5	7
	30	10	3	5
Totals.....		10	53	
Av. per response.....			5.3	
38	31	1	29	33
	32	2	9	12
	33	3	9	12
	34	4	4	6
	35	5	4	6
	36	6	3	5
	37	7	6	9
	38	8	4	6
	39	9	3	5
	40	10	9	11
Totals.....		10	80	
Av. per response.....			8	

TABLE V—(Continued)

SNAIL NO. 4—(Continued)

No. of days tested	No. for "food and pressure" stimulus, second series	No. of trial for day	No. of reactions per response	Duration of response in sec.
39	41	1	3	5
	42	2	3	5
	43	3	2	3
	44	4	2	3
	45	5	3	5
	46	6	2	3
	47	7	3	5
	48	8	2	3
	49	9	3	5
	50	10	1	1
Totals.....		10	24	
Av. per response.....			2.4	

Total number of trials.....	50
Total number of stimuli followed by response.....	43
Per cent of stimuli followed by response.....	86%
Total number of reactions.....	211
Average number of reactions per trial.....	4.22
Average number of reactions in only those trials in which response occurred.....	4.9
Total time of reactions in minutes.....	4.9
Average time per reaction in seconds.....	1.39
Average number of reactions per minute.....	43.16

SNAIL NO. 5

	No. of days tested	No. for "food and pressure" stimulus, second series	No. of trial for day	No. of reactions per response	Duration of response in sec.
Totals.....	35	1-10	10	21	26
Av. per response.....				4.2	
Totals.....	36	11-20	10	37	52
Av. per response.....				4.62	
Totals.....	37	21-30	10	64	91
Av. per response.....				6.4	
Totals.....	38	31-40	10	35	73
Av. per response.....				3.5	
Total number of trials.....					40
Total number of stimuli followed by response.....					33
Per cent of stimuli followed by response.....					82.5%
Total number of reactions.....					157
Average number of reactions per trial.....					3.92
Average number of reactions in only those trials in which response occurred.....					4.75
Total time of reactions in minutes.....					4.33

TABLE V—(Continued)

SNAIL NO. 5—(Continued)

Average time per reaction in seconds.....	1.54
Average number of reactions per minute.....	38.96
Summary Snails 4 and 5:	
Total number of stimuli (trials).....	90
Total number of stimuli followed by response.....	76
Per cent of stimuli followed by response.....	84.4%

Table V shows that movements of the mouth occurred in 76 out of 90 trials, with two individuals, or in 84.4% of the trials. The first series of tests in which the "conditioned" stimulus was used showed reactions occurring in 61 out of 100 trials or 61%, when food alone was used as a stimulus (Table II). These differences show the wearing away of the inhibition caused by the secondary stimulus (Table III) and by the experimental manipulation. The mean number of reactions per response for snails 4 and 5 was 4.84, 0.91 less than for the normal food response and 1.01 more than in the food-pressure series with trained snails. The inhibition of the response to food by the pressure stimulus has nearly disappeared (adaptation).

TABLE VI

Showing a summary of the reactions of the mouths of four individuals of *Physa gyrina* Say, resulting from (A) food stimulus alone, cf. Table II; (B) food and pressure used simultaneously, cf. Table III; (C) pressure alone, cf. Table IV; (D) food and pressure used simultaneously, 2d series, cf. Table V. The tests were made in filtered tap water on alternating days. The snails had been starved for 24 hours preceding the tests.

	Snail 6	Snail 7	Snail 8	Snail 14
A. Stimulus Food				
Total number of trials.....	42	50	60	60
Total number of stimuli followed by response..	8	38	47	32
Per cent of stimuli followed by reaction.....	19%	76%	78.3%	53.3%
Total number of reactions.....	52	247	143	350
Av. number of reactions per trial.....	1.23	5.14	2.38	5.83
Av. number of reactions in only those trials in which response occurred.....	6.5	6.5	3.4	10.93
Total time of reactions in minutes.....	1.13	5.33	3.23	7.35
Av. time per reaction in seconds.....	1.3	1.29	1.39	1.25
Av. number of reactions per minute.....	46.15	46.51	44.44	48
B. Stimulus Food and Pressure				
Total number of trials.....	250	250	253	250
Total number of stimuli followed by response..	33	82	53	47
Per cent of stimuli followed by reaction.....	13.2%	32.8%	20.9%	18.8%
Total number of reactions.....	65	337	84	182
Av. number of reactions per trial.....	0.26	1.34	0.03	0.72
Av. number of reactions in only those trials in which response occurred.....	1.96	4.1	1.58	3.87
Total time of reactions in minutes.....	1.2	6.56	1.5	3.6
Av. time per reaction in seconds.....	1.1	1.16	1.07	1.18
Av. number of reactions per minute.....	65.45	51.72	56.7	50.84

TABLE VI—(Continued)

	Snail 6	Snail 7	Snail 8	Snail 14
C. Stimulus Pressure				
Total number of trials.....	30	20	17	20
Total number of stimuli followed by response..	13	11	3	5
Per cent of stimuli followed by reaction.....	43.3%	55%	15.5%	25%
Total number of reactions.....	64	67	24	19
Av. number of reactions per trial.....	2.13	3.35	1.41	0.95
Av. number of reactions in only those trials in which response occurred.....	4.92	6.09	8	3.8
Total time of reactions in minutes.....	1.28	1.35	0.5	0.38
Av. time per reaction in seconds.....	1.2	1.2	1.25	1.21
Av. number of reactions per minute.....	64.16	64.16	48	49.54
D. Stimulus Food and Pressure (Second series)				
Total number of trials.....	50	50	50	50
Total number of stimuli followed by response..	16	36	44	25
Per cent of stimuli followed by reaction.....	32%	72%	88%	50%
Total number of reactions.....	123	173	158	120
Av. number of reactions per trial.....	2.46	3.46	3.16	2.4
Av. number of reactions in only those trials in which response occurred.....	7.68	4.8	3.59	4.8
Total time of reactions in minutes.....	2.51	3.78	3.28	2.53
Av. time per reaction in seconds.....	1.21	1.31	1.24	1.26
Av. number of reactions per minute.....	49.54	45.8	48.38	47.61

5. SUMMARY OF OBSERVATIONS

1. All observations and experiments were made on *Physa gyrina* Say while suspended from the surface film in a dish of filtered tap-water. In this position the lower surfaces of the foot and head are exposed and the movements of the mouth are visible.

2. When food (lettuce) or an inert substance (glass rod) is quickly applied to such a snail on or near the mouth and immediately withdrawn there results a response which consists of one or more opening and closing movements of the mouth. A single opening and closing of the mouth is referred to as a reaction. A response consists of one or many reactions in succession and takes place after the withdrawal of the stimulating substance.

3. Before the snails were used they were "tamed" by handling until they no longer visibly reacted to the mechanical disturbances incidental to the experiments.

4. All experiments were conducted under approximately uniform physical conditions, that is in filtered tap water at room temperature and with constant light intensity.

5. In all tests except those of the preliminary series each snail was used at intervals of forty-eight hours. It was allowed

to feed freely during the first half of this period but was given no food during the second half of the period. By thus controlling the food an attempt was made to have all snails in the same physiological state at the time of using them.

6. As a means of detecting variations in the physiological state a record was kept of the egg masses deposited by each snail, but no relation was found between the egg laying activity and any results of the experiments.

7. Each snail was distinguished by a number painted on the shell and a separate record was kept for each.

8. After a preliminary series of experiments involving six snails (Nos. 18-23), six other snails were used in the remaining experiments. For two of these (4, 5) complete records are presented in Tables II, III, IV, V, pp. 8, 13, 25 and 28. For the remaining four (6, 7, 8, 14) a summary of results is given in Table VI, p. 30.

9. Reactions of the mouth do not occur in the absence of external stimulation (preliminary test series). Six snails (Nos. 18-23, Table I, p. 6) were kept under observation for a total period of 32.75 hours (an average of 5.47 hours each), without stimulation. During this time but eight responses occurred with a total of 38 reactions. Three of the responses were seen to follow contact of the mouth of the snail with parts of the mucous track left by the animal in its normal movements on the surface film. The remaining five responses probably followed similar contact with this nearly invisible mucus. For experimental purposes the mouth response may be said to occur only as the result of the external stimulation. It is "involuntary." The error introduced into later experiments as a result of unobserved mucous stimulation is not enough to vitiate the experiments.

10. *The normal food-response.*—When food was applied to the mouth and at once withdrawn response followed in 61% of the tests (average for Snails 4 and 5). The average response consisted of 3.93 reactions. The average time of reaction was 1.25 sec. or 46.2 reactions per minute, Table II, p. 8.

11. The average number of reactions constituting the normal food-response varied with the individual snail as follows; No. 4, 3.48; No. 5, 4.35; Nos. 6 and 7, 6.5; No. 8, 3.4; No. 14, 10.93. The mean for all six snails is 5.86.

12. The average duration of a single reaction in the normal food-response is much more nearly the same in different individuals than is the number of reactions constituting a response. This average in seconds for the six snails in the order of paragraph 11 is, 1.29, 1.21, 1.3, 1.29, 1.39, 1.25. The values are obtained by dividing the duration of the response in seconds (as obtained with a stop watch) by the number of its component reactions. At the above rate the number of reactions per minute for the six snails would be 46.51, 45.9, 46.15, 46.51, 44.44, 48.0, or a mean of 46.25 reactions per minute.

13. An apparatus (food-pressure apparatus, fig. 1, Plate I) was devised for the simultaneous application of two unlike stimuli, food to the mouth and pressure to the foot at a fixed distance from the mouth.

14. *Pressure response of untrained snails.*—By means of the food-pressure apparatus pressure was applied to the foot at a fixed distance from the mouth. No stimulus was applied to any other part of the animal. In one hundred twenty applications of pressure to six snails (20 each) but four responses were obtained. Response thus occurred to 3.3% of the applications of pressure. The responses were probably due to chance stimulation by mucus. Response to pressure on the foot with the apparatus used occurs in so small a per cent of cases that it does not affect the experiments summarized below.

15. *Food-pressure response.*—When food was applied to the mouth and pressure to the foot at the same instant no response followed in the first 60 to 110 trials, in six series of 250 trials each (Snails 4, 5, 6, 7, 8 and 14). Response followed in the remaining trials of each series. In a total of 376 responses for the six snails, the average number of reactions per response was 3.42 as compared with 5.86 with the same snails when the food stimulus alone was used (Tables III and VI-B, pp. 13 and 30). The snails are referred to as "trained."

16. *Pressure response of trained snails.*—Forty-eight hours after the completion of their training, pressure alone was applied to the foot of the six trained snails (paragraph 15). In the case of Snail No. 4 response followed the first nine trials. The last two of these were separated by an interval of 48 hours from the first seven. The effect of training thus persisted for 96

hours. Similar results were obtained from Snails 5, 6, 7, 8 and 14 (Tables IV and VI-C, pp. 25 and 31).

17. *Cessation of pressure response in trained snails.*—Immediately following the ninth response to pressure of trained Snail No. 4 (paragraph 16) seven successive applications of pressure gave no response; 48 hours later ten applications gave no response; 96 hours after the last response ten applications failed to give any response. Similar results were obtained with the other five snails. *Cessation of response to pressure after training is sudden and final* (Tables IV and VI-C, pp. 25 and 31).

18. One hundred and twenty hours after the last response to pressure of Snail No. 4 (paragraph 16) a series of 50 trials was run on this snail by the simultaneous application of food and pressure. Response followed the first three trials and occurred in 86% of the subsequent trials (cf. paragraph 15), with an average of 4.9 reactions. Similar results were obtained with Snail No. 5. The average number of reactions per response was 4.84 for the two snails, 0.91 less than for the normal food response (paragraph 10) and 1.01 more than in the first food-pressure series (paragraph 15). The interference of the pressure stimulus with the response to food has nearly disappeared (Tables IV and VI-B, pp. 25 and 30).

19. The average number of reactions in the food-pressure response is less than the number in the normal food response. The numbers for the six snails in their numerical order is 3.96, 3.62, 1.96 (Table III, p. 13), 4.1, 1.58 and 3.87 (Table VI-B, p. 30). The average for the six snails is 3.18. Application of pressure to the foot at the same time with food to the mouth shortens the response.

20. The average duration of the reaction is less in the food-pressure responses than in the normal food response. The number per minute for the six snails in numerical order is 51.84, 51.92, 65.45, 51.72, 56.7, 50.84 (Tables III and VI-B, pp. 13 and 30). This is a mean distribution of 54.74, or 8.49 reactions per minute in excess of the normal food response (paragraph 12).

21. In the food-pressure series, the average number of reactions per ten trials increases irregularly toward the end of the series, except in the case of Snail No. 4. The average number of responses per ten trials shows a more uniform rise (Table III-A, p. 19, figs. 2-7, Plate II).

22. The average number of reactions per response resulting from the application of pressure alone to the foot of trained snails (paragraph 16) is greater than the average number resulting from the application of either food or food-pressure stimulation. The numbers for the six snails in their numerical order is 1.25, 4.0, 4.92, 6.09, 8.0, 3.8, or a mean of 4.67 reactions per response. These averages differ more than those of either food or food-pressure responses (Tables II, III and VI-A and VI-B, pp. 8, 13 and 30).

23. The average duration of the reactions resulting from the pressure stimulus alone on the foot of the trained snails is less than that of the normal food response. This is shown by the average number of reactions per minute for the six snails, 53.9, which is 7.65 more than with the normal food response (Tables IV and VI-C, pp. 25 and 31). In all trials the reaction duration is notably constant.

6. DISCUSSION

A. *Method.*—The experimental method used in this research will be called *the method of training by the use of simultaneous stimuli*. The term may be applied to any procedure in which two unlike stimuli are applied together or in immediate succession, to one of which the animal has previously responded by a definite reflex, but to the other of which it has failed to respond by the same reflex. The purpose is to establish response to the second stimulus alone. The stimuli may be referred to as primary and secondary and the primary stimulus may be called "conditioned" when used with the secondary (Pawlow's terms). The term, as thus defined, includes the salivary reflex method of Pawlow.

Comparison of the method with the salivary reflex method. The Pawlow method has been described (p. 2). It requires that the responses to the primary stimulus be a reflex, a so-called involuntary response, and that it be measurable. In order to meet the first requirement the response must, (a) occur only in response to external stimulation, (b) "always" occur in response to external stimulation; that is, it should occur with sufficient regularity to be available for experimental uses.

That the mouth response of *Physa* occurs only in response to stimulation of the mouth region has been shown. In six animals carefully guarded from such stimulation for a total

period of nearly thirty-three hours (about five and a half hours to each animal) the response occurred but eight times. Three of these responses were due to observed accidental stimulation and the rest were doubtless due to the same cause. On the other hand, as the tables show, stimulation of the mouth region induces the response in a sufficient percentage of trials to make it available for experimental purposes. The response is therefore a reflex available for these purposes.

The response of *Physa* to stimulation of the mouth region unaccompanied by other stimulation will be referred to as *the normal food response*. It consists of one or more opening and closing movements of the mouth. Each complete opening and closing movement is spoken of as a reaction. The response is measurable in terms of the number of its reactions as well as in duration. An inspection of the tables shows very great fluctuation in the numerical value of the response.

B. *Probable causes of fluctuation in response* are not difficult to find. They arise in part from the accidents of manipulation and are in part due to the physiological state of the snails. It is not an easy matter to apply a stimulus to the mouth of a moving snail, delicately suspended from the surface film. The difficulty is increased when two stimuli must be accurately placed at the same time. If the pressure is applied with the pressure fork strictly vertical, it is only that of the weight of the movable part of the apparatus and should be constant. Slight deviation from the vertical is inevitable and must result in occasional variation in pressure and in the manner in which the food reaches the mouth. These accidents should shorten response. That unskilled manipulation sometimes inhibits response entirely is clear from those cases marked x in the tables. It is fair to assume that they partially inhibit other responses. They depend in part on the physiological state of the operator. Added to these personal factors the tendencies to produce irregularity in response are vibrations of an unstable building due to slamming of doors, passing of street cars and movements of people. Other accidents prolong response. Probably at times portions of food are retained in the mouth of the snail and the response may be prolonged. At times accidental stimulation from unobserved mucus secreted by the snail, is added to that of the food on the hook and response is prolonged.

That the physiological state of the animal is in part responsible for fluctuations in response is indicated by the no-response shown in Tables II and III, pp. 8 and 13. Some of these were known to be due to mechanical disturbance and are marked x in the tables. Others were probably due to disturbance. Others again may be attributed to the physiological state of fatigue, although it is believed that the method of testing the snails alternately practically eliminated this element. It is noteworthy that a large percentage of the no-response trials occurs at the end of the day's series. This may be attributed to fatigue or adaptation—in either case a changed physiological state.

With a more delicate apparatus, and particularly with the elimination of external disturbances such as the vibrations caused by sudden jars beyond the limits of the experimental room, responses of more constant value might be obtained. It is quite possible that responses obtained by more refined methods would equal those of the salivary reflex method in constancy.

Throughout each of the tables it is to be noted that the duration of the individual reaction is reasonably uniform. It fluctuates mainly between 1.0 and 1.25 seconds. The fluctuations may be attributed to the method of timing with a stop watch. Were a better method available for the purpose, much greater uniformity in the reaction duration would doubtless appear. The uniformity actually found is striking and indicates that the use of the single reaction as a unit for measuring the response is justified. The unit is probably as accurate as the drop of saliva.

That the method described in this paper would yield results if used in the study of discrimination in the snails the writer does not doubt. It seems to offer for this purpose whatever advantage the Pawlow method affords although possibly in a less degree. It is also available in working out many of the details of the association process in a statistical way.

The data presented in this paper show that the behavior of the snail is modified by two processes, adaptation and learning.

Adaptation appears throughout the experiments and needs no extended discussion. It is enough to cite the following instances. Others will doubtless appear from a study of the tables.

(a) The snails became "tame." When first brought into the laboratory they expel the air from the lung and drop from

the surface film when in the least disturbed. After a time they no longer drop from the surface film under any moderate stimulation. To secure the expulsion of air from the lungs it is then necessary to use mechanical means.

(b) The snails recover from the inhibition of the mouth response due to manipulation. This appears in Table III, p. 13. Here inhibition is more marked in the first 60-80 trials, after which the snails recover and the number of reactions per response increases as the trials proceed until it reaches a maximum toward the middle of the series.

(c) A waning of response occurs in the series of trials shown in Table III, p. 13. Following a maximum number of reactions per response toward the middle of the series, the number gradually diminishes to the end of the series (figs. 2-7, Plate II). The snails are becoming adapted to the stimulus which is not followed by its wonted reward. The same thing occurs in the pressure response of trained snails shown in Table IV, p. 25. Here response is entirely lacking toward the end of the series.

(d) The absence of the response in the final trials on many days' series appears in Table III, p. 13. This may be due to fatigue, but is more likely the result of adaptation.

Other cases of adaptation in the snail appear in the paper of Dawson (1911) and in the work of Nagel (1894).

Learning, modifiability by association. Snails which gave no mouth response to pressure on the foot, were so modified by the simultaneous application of pressure to the foot and food to the mouth, that they then gave the mouth response to pressure on the foot. The effect of training with the simultaneous stimuli persisted for ninety-six hours after the cessation of training. Objectively this persistence of the training effect simulates memory. Its psychological implication is not discussed here.

The training process was accompanied by a shortening of the average duration of the individual reactions, in other words in an increase in their rate, as compared with the rate obtaining when the food stimulus alone was used. This acceleration is no doubt due to the unwonted stimulus applied to the foot and may be taken as evidence (if any is needed) that this stimulus was effective. The training process was accompanied by a reduction in the average number of reactions per response and

this again may be attributed to the unwonted foot-stimulus and may be accepted as evidence of its effectiveness.

Notable in the training series of trials of Snails 4 and 5 is the increase and subsequent decline in the average number of reactions per response after the initial inhibition. The average number of reactions per ten trials rises to a maximum in the neighborhood of the 150th trial and then declines. An examination of the graphs for these two snails (figs. 2, 3, 8 and 9, Plates II-III) suggests that the training has produced its maximum effect in the neighborhood of the 150th trial. If this were true a longer response to pressure only should be obtained from snails that had been trained for 150 trials than from those of longer training and this response might persist for a longer period. Whether this is actually the case could only be determined by comparing the response to pressure alone in a considerable number of snails with training periods of different lengths. A comparison of the graphs for Snails 4 and 5 with those for 6, 7, 8 and 14 shows that the latter are quite irregular. They show numerous maxima one of which commonly lies in the region of trial 150, but they do not support the view of a maximum training effect at a particular region in the series of trials. Thus an interpretation that seems wholly tenable from a study of two snails becomes untenable when the study is extended to a larger number of individuals. The maxima in the graphs for Snails 4 and 5 probably have their explanation in some undiscovered variation in the physiological state of these individuals. That taken by itself, it is interpretable in terms of learning may serve as a warning against generalizations based on experiments on one or two individuals. Nevertheless the relation of length of training and training effect in the snail may be worthy of further investigation.

II. MODIFIABILITY STUDIED BY THE LABYRINTH METHOD

1. INTRODUCTION

The evidence of learning in the snail, *Physa gyrina* Say, obtained by the use of the method of simultaneous stimuli suggested the query whether the snail could solve a simple labyrinth. Failure to solve the labyrinth would be evidence that this requires a capacity beyond that of forming simple associations. The labyrinth method has been used extensively

in nearly all groups of vertebrates, less extensively among invertebrates. Notable among the work on the latter group is that of Yerkes (1902) on the crayfish *Carcinus granulatus*, Yerkes and Huggins (1903) on habit formation in the crayfish *Cambarus affinis*, Fielde (1901) and Shepard (1916) on ants, and Yerkes (1912) on earthworms.

Just as the natural habits of rats in running about in narrow horizontal passages suggested to Small (1899) a series of such passages for experimental work, so the structure and habits of *Physa* suggested an upright or vertical path. *Physa* breathes air, but remains under water indefinitely when the so-called lung is full of air. When a new supply of oxygen is required it commonly seeks the surface of the water, although bubbles below the surface are sometimes "tapped" for air by the snail (Dawson, 1911). In order to gain the surface it ordinarily crawls up the stems of water plants growing in its natural habitat. It seemed then as though the tests might be placed on a purely natural basis by mechanically depriving the snail of air and placing it at the base of an upright path leading to the surface of the water. The animal's need for air would furnish the motive necessary to action. This need also suggested a natural punishment and reward for a correct or incorrect choice of paths, that is, the attainment of air at the end of the path or failure to get it.

2. APPARATUS AND MATERIAL*

The labyrinth used had the form of a rectangular U on an upright stem (fig. 14, Plate IV). One arm of the U reached the surface of the water while the other was so much shorter that the snail could not reach the surface from its tip. Various materials were tried out in the construction of the apparatus, such as cardboard coated with paraffin to protect it from the water, metal, mica and celluloid. The latter was finally selected because the surface of this material is like that of glass upon which snails crawl readily and also because it could be easily cut and manipulated should it be decided to alter the form of the path. Transparent celluloid 2.5 mm. in thickness was used in constructing the path (fig. 14, Plate IV). The upright

* The author is indebted to Professor George R. La Rue for advice in the mechanical construction of the labyrinth.

arms A and B were 8.5 mm. by 4.9 cm., the base of the U, C was 8.5 mm. by 4.25 cm. This rested on an upright stem D, 8.5 mm. by 3.6 cm., the base of which was cemented into a block of lead E, 2.1 cm. by 1.6 cm. by 6 mm. The celluloid part of the apparatus was carefully squared to the lead base E, before the cement was allowed to harden. Physa in crawling up anything but a broad surface has a tendency to crawl in a spiral direction, as may be readily demonstrated by allowing it to crawl up a glass rod placed upright in the aquarium. Should the animal ascend the stem of the labyrinth in a spiral path it would have the long or correct arm sometimes on its right and sometimes on its left. In order that the snail might have a choice of right and left paths on the labyrinth it was necessary to keep it confined to one side of the apparatus. In an attempt to accomplish this, the celluloid path was backed with galvanized, 0.5 inch-mesh wire netting, so cut that the entire path was bordered by a "picket fence" of wire, the pickets extending outward in the same plane as the path rather than at right angles to it. By cutting out every other "picket" the remaining wires were just far enough apart to make it mechanically impossible for the snail to pull its shell between them. This device proved an effective but not an absolute barrier, inasmuch as the animal occasionally managed to crawl over the end of a "picket," but the number of crossings became so reduced by its use, that this source of error was practically eliminated. The wire was cemented to the path by means of celluloid dissolved in acetone. The wires themselves and the lead base were also coated with this material, so that all parts of the completed apparatus with which the snail could come in contact were either made of celluloid or coated with it. This apparatus when in use was placed in the exact center of the experimental tank, thus bringing it directly under the centered light, so that the rays falling on each branch of the path A and B (fig. 14, Plate IV) were of equal intensity and thus the possibility of phototropism directing the course of the snail was avoided. Tap water at room temperature was used in the experimental tank. This temperature varied within the limits of a degree or two but it will appear later in the records of the experiments that the variations in temperature were the cause of no irregularities in the results.

In order to conduct the experiments under controlled lighting conditions and thus avoid any possible phototropic influence it was deemed advisable to create special conditions governing the light and keep them uniform throughout the experiments (fig. 15, Plate V). An experimental tank consisting of a battery jar 6 inches high and 4 inches in diameter was painted black on the outside and a level floor was obtained by means of a false bottom made of weighted paraffin. The center of the bottom was marked in the paraffin. This tank, during experimentation, was placed in the center of a "house" constructed from gray beaver-board fastened together with strips of gummed paper and painted dead black on the inside. The walls were 26 cm. by 38 cm. with a strip 19 cm. by 5 cm. cut from the lower edge on three sides for ventilation. For this purpose also small holes uniformly spaced were punched 2 cm. from the upper edge of the four sides. The fourth wall, the one next the operator, had a horizontal slit 2 cm. wide cut in it at 10 cm. from the top. The part of this wall below the slit was made removable. With the lower part of the fourth wall removed the operator could prepare experiments without taking the tank from the "house." When the movable part of the fourth wall was replaced there remained a slit 2 cm. in width, through which observations could be made. The top of the house was ground glass above which at a distance of 4 cm. was an 8 candle power electric light. This was centered over the house and held in a stationary position by means of a wooden frame. Two thicknesses of ordinary medium weight white paper were placed on top of the ground glass to further weaken and diffuse the light. The room in which the apparatus was located was darkened during experimentation. This apparatus was used without change throughout the experiments. The labyrinth itself was varied to conform with the requirements of each set of experiments. All snails used were tamed, individually numbered and kept under the same conditions as in the experiments with simultaneous stimuli.

3. EXPERIMENTS ON PREFERENCE

Two different kinds of preference tests were carried out. The first was to find whether a tendency to turn to the right or left existed. The asymmetry of the animal suggested the possibility.

The second test was to find any possible preference for an ascending or descending path.

A. *Experiments to test right or left preference.* In the first series an unpainted glass dish of beaker type, containing tap water at room temperature was placed in the centre of the experimental "house" and the ventilating spaces at the bottom of the walls of the "house" were blocked to exclude light. The air was forced from the lung of the snail by pressing its body gently back into its shell. It was then placed against the side of the dish at the four points of the compass in turn. It was allowed in each case to crawl up the side of the dish for air. The path was sketched and its right or left divergence from a perpendicular noted. The snails were handled with forceps and always placed on the horizontal bottom of the dish at right angles to the surface to be traveled. The mucous trail left on the sides of the dish was broken up after each trial by brushing the traveled surface with a clean camel's hair brush. Three snails, Nos. 15, 16 and 17, were used and four tests given each on two consecutive days. The record follows:

TABLE VII

Showing the deviation from a perpendicular shown by three individuals of *Physa gyrina* Say, in following an unconfined path up the side of a cylindrical glass dish in search of air.

	Trial No.	Snail 15	Snail 16	Snail 17
First day.....	1	Left	Right	Right
	2	Right	Left	Right
	3	Left	Right	Right
	4	Left	Left	Right
Second day.....	1	Left	Left	Right
	2	Left	Left	Left
	3	Right	Right	Right
	4	Right	Left	Right
Total.....		5L 3R	5L 3R	1L 7R
Total number of trials.....	24			
Total number of deviations to the right.....	13 approximately 54%			
Total number of deviations to the left.....	11 approximately 45%			

This experiment was based upon the normal behavior of the snail in its search for air; its path from the bottom of the dish to the surface was not limited in any way. Besides the record just given, three points of general interest were observed.

1. At no time during these experiments did the snail appear to make any effort to obtain air except at the surface of the water. Inasmuch as the depth of the water in the experimental tank was greater than that in the home aquarium, the observations conflict with those of Dawson (1911) which refer, however, to young snails.

2. The touching of the tentacles to the surface of the dish, at intervals, on either side of the path of the snail appeared in no case to alter the direction of the path.

3. There appeared to be no effort on the part of the snail under observation in these experiments, to re-distribute its weight by shifting the shell from side to side. Such shifting of the shell might exert a pull upon the body of the animal, strong enough to turn it in one direction more than another.

In the *second series* of preference tests the U-shaped labyrinth was used. Both of the upright arms reached the surface of the water so that a choice of either did not result in punishment. Six snails were used. They were divided into two groups of three each and tested on alternate days. This division was made because six snails could not be worked each day during the time at the disposal of the operator, and it was deemed advisable to have records from more than three snails. Each snail in each group of three was given ten trials per day. Enough fresh tap water at room temperature was placed in the experimental tank to reach the top of the arms of the U apparatus resting in the center of the dish. The snail was taken from the bacteria dish, in which it was kept at room temperature, and held in the hand while the body was gently pressed back into the shell by means of a dull metal seeker. In this way the snail was compelled to expel air from its lung. The animal, now negatively geotropic, was placed on the base of the U, E (fig. 14, Plate IV) by means of long forceps. The apex of the shell rested on base E while the opening of the shell touched the stem D. Thus when the snail came out of its shell, which it usually did almost immediately, it at once started to crawl up the stem D to the surface. At the top of D it turned either to the right or left on the cross bar C and then moved up either arm A or B to the surface of the water where it was permitted to obtain air. It was then lifted off with the hand as gently as possible and returned to its individual dish where it was

allowed to feed undisturbed while the other two snails of the group were tested in a similar way. After each test the celluloid apparatus was removed to a separate dish of water and thoroughly cleaned with a stiff brush in order to remove the mucous trail left by the tested snail and thus make it impossible for the next snail to follow the trail.

A complete record was made for each test given to each individual snail. Yerkes' method (1912), modified to suit the experiments, was adopted in making the records. Outlines of the labyrinth were drawn on separate slips of paper and the course chosen by each snail traced on one of these. The time required for the trip was taken with a stop-watch. The additional data of date, time of day, and temperature were added to the slip, and a record was also made of the eggs, if any, which had been deposited within twenty-four hours previous to the tests. It was thought that a later analysis of the records might show some relation between the physiological condition of the animal caused by ovulation, and the results of the experiments.

The following table shows the results obtained from a series of forty tests on each of six snails..

TABLE VIII

Showing the right and left preference of six individuals of *Physa gyrina* Say, which had been deprived of air and placed at the base of a vertical U-shaped path resting on an upright stem. Both arms of the U reached the surface. The horizontal of the U necessitated a choice of paths (fig. 14, Plate IV)

Snail No.	No. of days tested	No. of trials per day	No. of left choices	No. of right choices	Eggs
15	1	10	8	2	0
16		10	7	3	0
17		10	7	3	0
24	2	10	2	8	0
25		10	1	9	1
26		10	2	8	1
15	3	10	5	5	0
16		10	5	5	1
17		10	8	2	1
24	4	10	3	7	0
25		10	5	5	0
26		10	4	6	0
15	5	10	6	4	0
16		10	1	9	0
17		10	5	5	0

TABLE VIII—Continued

Snail No.	No. of days tested	No. of trials per day	No. of left choices	No. of right choices	Eggs
24	6	10	3	7	1
25		10	2	8	1
26		10	3	7	1
15	7	10	8	2	0
16		10	6	4	0
17		10	9	1	1

Total number of trials..... 240

Total number of left turns..... 116 approximately 48%

Total number of right turns..... 124 approximately 52%

B. *Experiments to test preference for an ascending or descending path.* If the cross bar of the U should not be horizontal, the snail after ascending the stem would have a choice of a descending path on one side and an ascending path on the other. In a set of preference tests an attempt was made to determine whether the animal showed preference for either of these paths. In order to tilt the labyrinth at various angles the experimental tank was placed on a small board, 8 1-2 in. by 10 in. by 1-4 in., made of three layers to insure an unwarped surface. One end of the board was pierced by two screw eyes set one inch from the edge. By turning these screws the board, together with the apparatus resting upon it, could be readily adjusted to any angle. The angle used in each experiment was measured with a Sterret spirit level. The slant of the right and left sides of the path was frequently and irregularly reversed in order to avoid any possible right and left habit formation during experimentation.

These tests were performed in the same way as those already described and the records were similar. The tabulated results follow.

TABLE IX

Showing the tendency of six individuals of *Physa gyrina* Say to follow an ascending or a descending path when the apparatus was tilted. The U-shaped apparatus was used and the angle made by the cross bar of the U with a horizontal measure. Both arms of the U reached the surface.

Snail No.	Angle of inclination to horizontal of cross bar of U-shaped labyrinth									
	0°-1°		1°-2°		3°-4°		5°-6°		7°-8°	
	up	down	up	down	up	down	up	down	up	down
15	37	23	3	7	7	3	5	5	8	2
16	23	27	2	8	4	6	5	5	6	4
17	38	22	6	4	5	5	6	4	6	4
24	36	24	6	4	5	5	6	4	10	0
25	32	28	4	6	4	6	7	3	8	2
26	32	28	4	6	6	4	6	4	5	5
Totals.....	208	152	25	35	31	29	35	29	43	17
	58%	42%	42%	58%	52%	48%	58%	42%	72%	28%

Table IX shows that when six individuals were given a choice of an ascending or a descending path, both of which ended at the surface, and when the angle of deviation from a horizontal at the point of selection was not greater than 8 degrees, the ascending path was chosen in 342 trials out of 600 or in 57% of the trials. There appears to be a strong tendency to follow the upward path only at the angle 7-8 degrees. In further experiments the cross bar of the U was kept horizontal.

4. EXPERIMENTS ON LEARNING THE U-SHAPED LABYRINTH; CHOICE OF RIGHT AND LEFT PATH; PUNISHMENT FAILURE TO GET AIR

Inasmuch as the snails showed a slight tendency to turn toward the right in the preference tests, the right arm of the U-shaped path was now shortened by cutting 2 cm. from the upper end. A choice of this arm would lead to punishment (failure to get air) and would be a wrong choice. When a wrong choice was made the snail had to retrace its path to the point of choice where it usually continued its course along the horizontal bar and up the long arm to the surface of the water. This was the only modification made in the apparatus for the learning experiments. The method of handling the animals and the apparatus was the same as in the preceding tests. Three snails were used in these experiments. They were at first tested every other day. The three snails were worked in turn and as many trips given each as was possible in the time at the disposal of

the experimenter. The number of trips per day varied considerably because it was found that sometimes individual snails refused to start up the labyrinth. At such times they were frequently allowed to remain at the base of the stem for a considerable length of time in the hope that the tests might be continued in regular order. Sometimes, however, work on the individual snail so affected had to be discontinued for the day. When a snail lost its hold on the labyrinth and dropped to the bottom of the tank during its test, it was immediately started up again and this second trip was given the same serial number as the previous one with a small letter after it. The same method of recording the observations was used as that described for the preference tests. A record was also made of the "latent" period, that is, the time between the placing of the animal at the base of the stem and the actual start on the upward path. Although not noted in the tabulations, this record appears to have no bearing on the results of the experiments, since fluctuations were probably due in part to the fact that the snail still retained a small amount of air in its lung, so that its need for a fresh supply was less urgent. In constructing curves based upon these records the percentage of errors or wrong choices for each snail per day was used. An analysis of the records appears to show no relation between the latent periods, oviposition, the time required for the trip and the number of errors.

TABLE X

Showing the paths followed by three individuals of *Physa gyrina* Say in attempting to reach the surface of the water for air. U-shaped labyrinth used. The right arm was so short that the snail could not obtain air by following it (punishment), while air might be obtained at the top of the left arm (reward). The apparatus was cleaned between trials.

SNAIL No. 1				
No. of days tested	No. of trial for series	No. of trial for day	No. of correct or left choices	No. of incorrect or right choices
*1	1	1	1	0
	2	2	1	0
	3	3	0	1
	4	4	1	0
	5	5	1	0
	6	6	1	0
Totals.....		6	5 (83%)	1 (16%)

TABLE X—(Continued)

SNAIL No. 1—(Continued)				
No. of days tested	No. of trial for series	No. of trial for day	No. of correct or left choices	No. of incorrect or right choices
*2	7	1	1	0
	8	2	1	0
	9	3	0	1
	10	4	1	0
	11	5	1	0
	12	6	0	1
	13	7	1	0
	14	8	1	0
Totals.....		8	6 (75%)	2 (25%)
*3	15	1	1	0
	16	2	1	0
	17	3	1	0
	18	4	1	0
	19	5	1	0
	20	6	1	0
	21	7	0	1
Totals.....		7	6 (85%)	1 (14%)
*4	22	1	1	0
	23	2	0	1
	24	2a	1	0
	25	2b	1	0
	26	3	1	0
	27	4	1	0
	28	5	1	0
Totals.....		7	6 (85%)	1 (14%)
5	29	1	1	0
	30	2	1	0
	31	3	1	0
	32	4	1	0
	33	5	0	1
	34	5a	1	0
Totals.....		6	5 (83%)	1 (16%)
*6	35	1	1	0
	36	2	1	0
	37	3	1	0
	38	4	0	1
	39	4a	0	1
	40	4b	0	1
	41	4c	1	0
	42	5	0	1
Totals.....		8	4 (50%)	4 (50%)

TABLE X—(Continued)

SNAIL No. 1—(Continued)				
No. of days tested	No. of trial for series	No. of trial for day	No. of correct or left choices	No. of incorrect or right choices
7	43	1	1	0
	44	2	0	1
	45	3	1	0
	46	4	1	0
	47	5	1	0
	48	6	0	1
	49	6a	0	1
	50	6b	1	0
Totals.....		8	5 (62%)	3 (37%)
8	51	1	1	0
	52	2	1	0
	53	3	1	0
	54	4	1	0
	55	5	1	0
	56	6	0	1
	57	7	0	1
Totals.....		7	5 (71%)	2 (28%)
*9	58	1	1	0
	59	2	1	0
	60	3	1	0
	61	4	1	0
	62	5	1	0
Totals.....		5	5 (100%)	0
10	63	1	1	0
	64	2	0	1
	65	3	0	1
	66	4	1	0
	67	5	1	0
Totals.....		5	3 (60%)	2 (40%)
*11	68	1	1	0
	69	2	1	0
	70	3	1	0
	71	4	0	1
	72	5	0	1
	73	6	0	1
	74	6a	1	0
Totals.....		7	4 (57%)	3 (42%)
*12	75	1	0	1
	76	2	0	1
	77	3	0	1
	78	4	0	1
	79	5	1	0
	80	6	0	1
	81	7	1	0
Totals.....		7	2 (28%)	5 (71%)

TABLE X—(Continued)

SNAIL NO. 1—(Continued)

No. of days tested	No. of trial for series	No. of trial for day	No. of correct or left choices	No. of incorrect or right choices
13	82	1	1	0
	83	2	0	1
	84	3	0	1
	85	4	0	1
	86	5	1	0
	87	6	0	1
	88	7	0	1
Totals.....		7	2 (28%)	5 (71%)
*14	89	1	1	0
	90	2	0	1
	91	3	0	1
	92	3a	0	1
	93	3b	0	1
	94	3c	0	1
	95	3d	0	1
	96	3e	0	1
	97	4	0	1
	98	5	0	1
	99	6	0	1
Totals.....		11	1 (9%)	10 (90%)
*15	100	1	0	1
	101	2	0	1
	102	3	0	1
	103	3a	1	0
Totals.....		4	1 (25%)	3 (75%)
16	104	1	1	0
	105	2	1	0
	106	3	1	0
	107	4	1	0
	108	5	1	0
	109	6	0	1
	110	7	0	1
	111	7a	1	0
Totals.....		8	6 (75%)	2 (25%)
*17	112	1	1	0
	113	2	0	1
	114	3	1	0
	115	4	0	1
	116	5	0	1
	117	6	1	0
	118	7	1	0
Totals.....		7	4 (57%)	3 (42%)
18	119	1	1	0
	120	2	1	0
	121	3	1	0
	122	4	0	1
	123	5	0	1
Totals.....		5	3 (60%)	2 (40%)

TABLE X—(Continued)

SNAIL NO. 1—(Continued)

No. of days tested	No. of trial for series	No. of trial for day	No. of correct or left choices	No. of incorrect or right choices
19	124	1	0	1
	125	2	0	1
	126	3	0	1
	127	4	0	1
	128	5	1	0
Totals.....		5	1 (20%)	4 (80%)
20	129	1	0	1
	130	1a	1	0
	131	2	1	0
	132	3	0	1
	133	4	1	0
	134	5	1	0
Totals.....		6	4 (66%)	2 (33%)
*21	135	1	1	0
	136	2	0	1
	137	2a	1	0
	138	3	1	0
	139	4	1	0
	140	5	0	1
Totals.....		6	4 (66%)	2 (33%)
*22	141	1	1	0
	142	2	1	0
	143	3	1	0
	144	4	1	0
	145	5	0	1
	146	5a	1	0
Totals.....		6	5 (83%)	1 (16%)
23	147	1	1	0
	148	2	0	1
	149	3	1	0
	150	4	1	0
	151	5	1	0
	152	6	1	0
	153	7	0	1
	154	7a	1	0
Totals.....		8	6 (75%)	2 (25%)
24	155	1	0	1
	156	2	0	1
	157	3	0	1
	158	3a	0	1
	159	3b	1	0
	160	4	0	1
Totals.....		6	1 (16%)	5 (83%)

TABLE X—(Continued)

SNAIL NO. 1—(Continued)

No. of days tested	No. of trial for series	No. of trial for day	No. of correct or left choices	No. of incorrect or right choices
25	161	1	0	1
	162	2	0	1
	163	3	0	1
	164	4	0	1
	165	5	0	1
Totals.....		5	0	5 (100%)
26	166	1	0	1
	167	2	1	0
	168	3	0	1
	169	3a	0	1
	170	3b	1	0
Totals.....		5	2 (40%)	3 (60%)
*27	171	1	1	0
	172	2	0	1
	173	3	0	1
	174	3a	0	1
	175	4	0	1
Totals.....		5	1 (20%)	4 (80%)
28	176	1	0	1
	177	2	0	1
	178	3	0	1
	179	4	0	1
	180	5	0	1
Totals.....		5	0	0 (100%)
29	181	1	0	1
	182	2	1	0
	183	3	0	1
	184	4	0	1
Totals.....		4	1 (25%)	3 (75%)
30	185	1	0	1
	186	2	0	1
	187	3	0	1
Totals.....		3	0	3 (100%)
31	188	1	1	0
	189	2	1	0
	190	3	1	0
	191	4	0	1
	192	5	0	1
Totals.....		5	3 (60%)	2 (40%)
32	193	1	0	1
	194	2	0	1
	195	3	1	0
	196	4	1	0
	197	5	1	0
Totals.....		5	3 (60%)	2 (40%)

TABLE X—(Continued)

SNAIL No. 1—(Continued)

No. of days tested	No. of trial for series	No. of trial for day	No. of correct or left choices	No. of incorrect or right choices
*33	198	1	0	1
	199	1a	0	1
	200	2	0	1
	201	3	0	1
	202	4	0	1
Totals.....		5	0	5 (100%)
34	203	1	0	1
	204	1a	0	1
	205	2	0	1
	206	2a	1	0
	207	3	0	1
Totals.....		5	1 (20%)	4 (80%)
35	208	1	1	0
	209	2	0	1
	210	3	1	0
	211	4	1	0
Totals.....		4	3 (75%)	1 (25%)
*36	212	1	1	0
	213	2	1	0
	214	3	0	1
	215	4	0	1
	216	5	0	1
Totals.....		5	2 (40%)	3 (60%)
37	217	1	0	1
	218	2	0	1
	219	2a	0	1
	220	3	1	0
	221	4	0	1
Totals.....		5	1 (20%)	4 (80%)
*38	222	1	0	1
	223	1a	1	0
	224	2	1	0
	225	3	0	1
	226	4	0	1
Totals.....		5	2 (40%)	3 (60%)
39	227	1	1	0
	228	2	0	1
	229	3	0	1
	230	3a	1	0
	231	4	1	0
Totals.....		5	3 (60%)	2 (40%)

TABLE X—(Continued)

SNAIL NO. 1—(Continued)

No. of days tested	No. of trial for series	No. of trial for day	No. of correct or left choices	No. of incorrect or right choices
40	232	1	1	0
	233	2	0	1
	234	3	0	1
	235	3a	0	1
	236	4	1	0
Totals.....		5	2 (40%)	3 (60%)
41	237	1	1	0
	238	2	1	0
	239	3	0	1
	240	4	0	1
	241	5	0	1
Totals.....		5	2 (40%)	3 (60%)
42	242	1	1	0
	243	2	0	1
	244	3	0	1
	245	4	0	1
	246	5	1	0
Totals.....		5	2 (40%)	3 (60%)
*43	247	1	1	0
	248	2	1	0
	249	3	1	0
	250	4	0	1
	251	5	0	1
Totals.....		5	3 (60%)	2 (40%)
44	252	1	1	0
	253	2	1	0
	254	3	1	0
	255	4	0	1
	256	5	0	1
	257	6	1	0
	258	7	0	1
	259	8	0	1
Totals.....		8	4 (50%)	4 (50%)
45	260	1	0	1
	261	2	1	0
	262	3	0	1
Totals.....		3	1 (33%)	2 (66%)
*46	263	1	0	1
	264	2	1	0
	265	3	0	1
	266	3a	0	1
	267	4	0	1
	268	5	0	1
	269	6	0	1
	270	6a	0	1
Totals.....		8	1 (12%)	7 (87%)

TABLE X—(Continued)

SNAIL NO. 1—(Continued)

No. of days tested	No. of trial for series	No. of trial for day	No. of correct or left choices	No. of incorrect or right choices
47	271	1	1	0
	272	2	0	1
	273	2a	0	1
	274	2b	0	1
	275	3	0	1
	276	4	0	1
Totals.....		6	1 (16%)	5 (83%)
48	277	1	1	0
	278	2	0	1
	279	3	0	1
	280	4	1	0
	281	5	1	0
	282	6	1	0
Totals.....		6	4 (66%)	2 (33%)

SUMMARY—SNAIL NO. 1

No. of days tested	No. of trials	Correct or left choices	Incorrect or right choices
*1	6	5	1
*2	8	6	2
*3	7	6	1
*4	7	6	1
5	6	5	1
*6	8	4	4
7	8	5	3
8	7	5	2
*9	5	5	0
10	5	3	2
*11	7	4	3
*12	7	2	5
13	7	2	5
*14	11	1	10
*15	4	1	3
16	8	6	2
*17	7	4	3
18	5	3	2
19	5	1	4
20	6	4	2
*21	6	4	2
22	6	5	1
23	8	6	2
24	6	1	5
25	5	0	5
26	5	2	3
*27	5	1	4
28	5	0	5
29	4	1	3
30	3	0	3

AN ANALYSIS OF THE LEARNING PROCESS IN THE SNAIL 57

TABLE X—(Continued)

SUMMARY—SNAIL NO. 1—(Continued)

No. of days tested	No. of trials	Correct or left choices	Incorrect or right choices
31	5	3	2
32	5	3	2
*33	5	0	5
34	5	1	4
35	4	3	1
*36	5	2	3
37	5	1	4
*38	5	2	3
39	5	3	2
40	5	2	3
41	5	2	3
42	5	2	3
*43	5	3	2
44	8	4	4
45	3	1	2
*46	8	1	7
47	6	1	5
48	6	4	2

Total number of trials..... 282

Total number of correct or left choices..... 136 approximately 48%

Total number of incorrect or right choices..... 146 approximately 52%

SUMMARY—SNAIL NO. 2

No. of days tested	No. of trials	Correct or left choices	Incorrect or right choices
1	5	4	1
*2	8	8	0
*3	7	3	4
*4	5	3	2
5	6	2	4
*6	5	5	0
7	6	3	2
8	6	3	3
*9	5	2	3
10	6	1	5
*11	9	3	6
*12	8	4	4
13	7	4	3
14	7	4	3
*15	3	2	1
16	9	4	5
17	7	4	3
*18	7	2	5
19	5	4	1
20	5	2	3
21	5	3	2
*22	7	1	6
23	7	6	1

TABLE X—(Continued)

SUMMARY—SNAIL NO. 2—(Continued)

No. of days tested	No. of trials	Correct or left choices	Incorrect or right choices
24	4	0	4
25	5	2	3
26	4	2	2
*27	5	1	4
28	5	0	5
29	4	1	3
*30	3	0	3
31	4	2	2
32	5	1	4
33	5	0	5
*34	5	1	4
*35	4	1	3
36	5	2	3
37	5	0	5
*38	5	1	4
39	5	1	4
*40	5	0	5
41	5	2	3
42	5	3	2
43	5	4	1
*44	5	0	5
45	8	4	4
46	3	0	3
47	7	4	3
48	6	1	5
49	6	1	5
*50	10	2	8
51	5	1	4
52	7	2	5
53	6	0	6
54	6	1	5

Total number of trials..... 307
 Total number of correct or left choices..... 117 approximately 38%
 Total number of incorrect or right choices..... 190 approximately 62%

SUMMARY—SNAIL NO. 3

No. of days tested	No. of trials	Correct or left choices	Incorrect or right choices
*1	2	1	1
*2	7	4	3
3	6	5	1
*4	5	0	5
5	6	1	5
6	7	2	5
7	5	2	3
8	6	1	5
9	5	4	1
10	5	2	3

TABLE X—(Continued)

SUMMARY—SNAIL NO. 3—(Continued)

No. of days tested	No. of trials	Correct or left choices	Incorrect or right choices
*11	6	3	3
*12	7	4	3
13	7	2	5
14	7	3	4
*15	3	1	2
16	7	3	4
17	7	3	4
*18	5	1	4
19	5	2	3
20	5	2	3
21	4	2	2
22	4	1	3
*23	8	6	2
24	4	3	1
*25	7	2	5
26	5	2	3
*27	5	2	3
28	5	2	3
*29	5	1	4
30	5	1	4
31	4	3	1
32	5	1	4
*33	5	1	4
34	5	2	3
35	4	0	4
36	5	3	2
37	5	0	5
*38	5	2	3
*39	5	4	1
40	5	1	4
*41	5	4	1
42	5	1	4
43	5	1	4
44	5	1	4
45	8	2	6
46	3	1	2
47	7	6	1
48	5	3	2
49	6	1	5
*50	10	3	7
51	8	0	8
52	7	3	4
53	6	0	6
*54	6	2	4

Total number of trials..... 299
 Total number of correct or left choices..... 113 approximately 38%
 Total number of incorrect or right choices..... 186 approximately 62%

* Indicates that an egg mass was deposited by the snail during the 24 hours immediately preceding the tests on the day marked.

TABLE X-A

SUMMARY OF LEFT-RIGHT DISCRIMINATION TESTS			
	Snail No. 1	Snail No. 2	Snail No. 3
Total number of trials.....	282	307	299
Per cent of incorrect choices.....	52	62	62

Table X shows that in a total of 888 trials on three individuals of *Physa*, in a series of tests offering a choice of right and left paths, with a reward for the correct choice (left), the incorrect path (right) was followed in 58.8% of the trials. The graphs (figs. 16-18, Plate VI) show very great irregularity in the time distribution of the right and wrong choices. There are days when the record is perfect, other days when all choices are wrong. Between these is every intermediate condition. A slight excess of incorrect choices is to be expected on account of the possible tendency to turn to the right shown in the right-left preference tests. *These records show no indication of learning.*

5. EXPERIMENTS WITH THE Y-SHAPED LABYRINTH: ROUGHNESS OF PATH AS A WARNING SIGN: ELECTRIC SHOCK PUNISHMENT

It seemed either that the problem itself was too difficult or that the immediate demand for air (punishment) was not great enough to force its solution. In its natural habitat the snail often depends on plant stems as a means of reaching the surface of the water when a fresh supply of oxygen is needed. The stems must frequently be too short. The problem is then familiar to the snail and should be easy. To make the problem still easier it was decided to determine whether or not the snail could form a simple association between two stimuli upon a labyrinth that it had failed to solve. The labyrinth was changed as follows: 1. A Y-shaped labyrinth was used so that the snail could make a choice immediately upon reaching the top of the stem of the Y. The Y was made of glass tubing. 2. The snail was not confined to one side of it. Owing to the spiral course followed by the ascending animal, there was no right and left choice. 3. One side of the Y was made rough and the other left smooth. The training series had shown that the snail feels the delicate pressure on the foot of the three-pronged pressure fork of the food-pressure apparatus (fig. 1, Plate I). It should

therefore feel the difference between a rough and smooth path. 4. For the failure-to-get-air punishment with the U-shaped labyrinth there was substituted the electric shock. Reward was the getting of air.

The problem resolved itself then, into an attempt to determine whether or not the snail could form a simple association between two dissimilar stimuli one of which (punishment) followed the other (warning). It has already been shown that the snail can form a weak association between two stimuli simultaneously applied (food-pressure series). Can it then bridge over an interval between two stimuli one of which follows the other almost immediately?

Glass tubing, 5 mm. in diameter, in the form of a Y was used. One arm of the Y, 4.5 cm. in length, reached the surface of the water. The other arm, 3.5 cm. in length, was short enough so that the animals could not reach the surface. The stem of the Y was 3 cm. long. Two (No. 23) silk-insulated copper wires were passed through the stem to the upper end of the short arm, where they connected with two fine platinum wire (No. 26) rings passing around the end of the short arm close enough together so that an electric current could be passed between them, when proper connections were made. The upper ends of both arms were then closed with sealing wax to keep out the water. A hollow base, 4 cm. by 2 cm. by 1.5 cm., of lead was made, in order to permit an outlet for the wires. These passed from the lower end of the stem of the Y into a rubber tube which carried them, protected from the water, through the metal base, along the floor of the experimental tank and upward to the outside. A direct current of 0.2 amperes was taken from 220 volt mains through a lamp of 1100 ohms in series with 8 ohms of other resistance. From the terminals of 8 ohms a second circuit was taken including a rheostat of 1800 ohms, a receiving switch, a key and the Y apparatus. When no current was drawn through this second circuit the voltage between the two platinum wires would be 1.6 volts. The maximum current which could be drawn through the circuit by short-circuiting the two platinum wires was slightly less (actually 16-18) than 0.001 amperes or 1 milliampere*. It was

*The author is indebted to Professor A. W. Smith for measuring the electric current used in the experiments.

found that this current caused the snails to draw backward into their shells for a little way. They usually resumed their normal movements in a short time. Rarely they retracted so much that they lost their hold on the glass tubing and dropped to the bottom of the tank. The short arm of the Y from the point of divergence to within a millimeter or so of the platinum wires was roughened by means of a band of block tin, 2 mm. in width and 1 mm. thick, passing around it in a spiral. The metal was then insulated with a coat of liquid celluloid and further roughened by a coat of coarse cutting sand imbedded in the celluloid before it hardened. These precautions appeared desirable because it seemed possible that enough mucus might be secreted by the snail in crawling over sand alone, to fill in the spaces between the grains and thus make a smooth surface upon which to travel. This hardly seemed possible over the ridges of metal used, inasmuch as they were far enough separated so that the snail had to sink down into the space between, in passing over them. If the snail turned toward the short arm at the top of the stem it immediately came in contact with the rough ridges and a little later with the bare electric wires, at which point the punishment was administered by closing the circuit. No attempt was made to keep the snail on one side of the apparatus. It sometimes crawled in an irregular spiral but frequently kept on one side. The whole apparatus was made shorter than the celluloid labyrinth previously used, in order to shorten the time used in each test and thus make a greater number of tests possible in a given time. The method of manipulation and cleaning the apparatus was the same as in the previous tests, and in order to avoid any possible tendency of the snail to follow the same path in consecutive trips, the labyrinth was frequently turned so that the short arm was as often toward the left as the right. The "map" method before described was adopted in making the records. Four snails were used and a total of 664 trials given. The curves (figs. 19-22, Plate VII) were based upon the percentage of errors for each snail per day.

TABLE XI

Showing the number of correct and incorrect turns made by three individuals of *Physa gyrina* Say, in their attempts to reach the surface of the water on the Y apparatus. Error was punished by an electric shock. The warning stimulus was roughness. The apparatus was cleaned between trials.

SNAIL No. 9				
No. of days tested	No. of trial for series	No. of trial for day	No. of correct choices	No. of incorrect choices
1	1	1	1	0
	2	2	0	1
	3	3	0	1
Totals.....		3	1 (33%)	2 (66%)
2	4	1	0	1
3	5	1	1	0
	6	2	1	0
	7	3	1	0
Totals.....		3	3 (100%)	0
4	8	1	1	0
	9	2	0	1
	10	2a	0	1
	11	2b	0	1
	12	3	0	1
Totals.....		5	1 (20%)	4 (80%)
*5	13	1	0	1
	14	1a	1	0
	15	2	0	1
	16	3	0	1
	17	3a	0	1
Totals.....		5	1 (20%)	4 (80%)
*6	18	1	0	1
	19	1a	1	0
	20	2	0	1
	21	3	0	1
Totals.....		4	1 (25%)	3 (75%)
7	22	1	1	0
	23	2	0	1
	24	2a	0	1
	25	2b	1	0
	26	3	0	1
	27	3a	0	1
	28	4	0	1
Totals.....		7	3 (42%)	4 (57%)
8	29	1	1	0
	30	2	0	1
	31	3	0	1
	32	3a	0	1
	33	3b	1	0
	34	4	1	0
Totals.....		6	3 (50%)	3 (50%)

TABLE XI—(Continued)

SNAIL NO. 9—(Continued)

No. of days tested	No. of trial for series	No. of trial for day	No. of correct choices	No. of incorrect choices
9	35	1	1	0
	36	2	1	0
	37	3	1	0
	38	4	0	1
	39	5	0	1
	40	5a	0	1
	41	5b	1	0
Totals.....		7	4 (57%)	3 (42%)
10	42	1	1	0
	43	2	1	0
Totals.....		2	2 (100%)	0
11	44	1	0	1
	45	2	0	1
	46	2a	0	1
	47	3	0	1
	48	3a	0	1
Totals.....		5	0	5 (100%)
12	49	1	1	0
	50	2	1	0
	51	3	0	1
	52	4	0	1
	53	4a	0	1
	54	4b	1	0
	55	5	0	1
	56	5a	0	1
Totals.....		8	3 (37%)	5 (62%)
13	57	1	1	0
	58	2	1	0
	59	3	1	0
Totals.....		3	3 (100%)	0
14	60	1	0	1
	61	1a	1	0
	62	2	0	1
	63	2a	0	1
Totals.....		4	1 (25%)	3 (75%)
15	64	1	1	0
	65	2	0	1
	66	2a	0	1
	67	2b	1	0
	68	3	1	0
Totals.....		5	3 (60%)	2 (40%)

TABLE XI—(Continued)

SNAIL NO. 9—(Continued)

No. of days tested	No. of trial for series	No. of trial for day	No. of correct choices	No. of incorrect choices
16	69	1	1	0
	70	2	0	1
	71	2a	0	1
	72	2b	0	1
	73	2c	1	0
	74	3	1	0
Totals.....		6	3 (50%)	3 (50%)
17	75	1	1	0
	76	2	1	0
	77	3	1	0
	78	4	0	1
	79	4a	0	1
Totals.....		5	3 (60%)	2 (40%)
18	80	1	0	1
	81	1a	1	0
	82	2	0	1
	83	3	1	0
	84	4	0	1
	85	4a	1	0
	86	5	0	1
Totals.....		7	3 (42%)	4 (57%)
19	87	1	0	1
	88	2	1	0
	89	3	0	1
	90	3a	0	1
	91	3b	1	0
Totals.....		5	2 (40%)	3 (60%)
20	92	1	1	0
	93	2	0	1
	94	2a	0	1
	95	2b	1	0
Totals.....		4	2 (50%)	2 (50%)
21	96	1	0	1
	97	1a	1	0
	98	2	1	0
	99	3	1	0
	100	4	0	1
Totals.....		5	3 (60%)	2 (40%)
22	101	1	0	1
	102	2	1	0
	103	3	0	1
	104	3a	1	0
	105	4	1	0
	106	5	1	0
Totals.....		6	4 (66%)	2 (33%)

TABLE XI—(Continued)
SNAIL No. 9—(Continued)

No. of days tested	No. of trial for series	No. of trial for day	No. of correct choices	No. of incorrect choices
23	107	1	0	1
	108	1a	1	0
	109	2	1	0
	110	3	0	1
	111	3a	0	1
	112	3b	1	0
	113	4	1	0
Totals.....		7	4 (57%)	3 (42%)
24	114	1	0	1
	115	1a	0	1
	116	1b	0	1
	117	1c	1	0
	118	2	1	0
Totals.....		5	2 (40%)	3 (60%)
25	119	1	0	1
	120	1a	1	0
	121	2	1	0
	122	3	1	0
	123	4	1	0
	124	5	1	0
	125	6	0	1
	126	6a	0	1
	127	6b	0	1
	128	6c	1	0
Totals.....		10	6 (60%)	4 (40%)
26	129	1	1	0
	130	2	1	0
	131	3	1	0
	132	4	1	0
	133	5	0	1
	134	5a	0	1
	135	5b	1	0
Totals.....		7	5 (71%)	2 (28%)
27	136	1	0	1
	137	2	1	0
	138	3	0	1
	139	3a	0	1
	140	3b	0	1
	141	3c	0	1
	142	3d	1	0
	143	4	1	0
Totals.....		8	3 (37%)	5 (62%)
28	144	1	0	1
	145	1a	0	1
	146	1b	0	1
	147	1c	0	1
	148	2	0	1
	149	2a	0	1
	150	2b	1	0
Totals.....		7	2 (28%)	5 (71%)

AN ANALYSIS OF THE LEARNING PROCESS IN THE SNAIL 67

TABLE XI—(Continued)

SNAIL No. 9—(Continued)

No. of days tested	No. of trial for series	No. of trial for day	No. of correct choices	No. of incorrect choices
29	151	1	0	1
	152	1a	0	1
	153	1b	0	1
	154	1c	1	0
Totals.....		4	1 (25%)	3 (75%)
30	155	1	0	1
	156	1a	1	0
	157	2	1	0
	158	3	0	1
	159	3a	0	1
	160	4	1	0
	161	5	1	0
Totals.....		7	4 (57%)	3 (42%)
31	162	1	0	1
	163	2	1	0
	164	3	1	0
	165	4	0	1
	166	4a	0	1
	167	4b	0	1
	168	4c	0	1
Totals.....		7	2 (28%)	5 (71%)
32	169	1	0	1
	170	1a	0	1
	171	1b	1	0
	172	2	0	1
	173	2a	1	0
	174	3	1	0
	175	4	1	0
	176	5	1	0
	177	6	0	1
	178	6a	0	1
Totals....		10	5 (50%)	5 (50%)
33	179	1	0	1
	180	1a	0	1
	181	1b	0	1
	182	1c	1	0
	183	2	1	0
	184	3	1	0
	185	4	0	1
	186	4a	1	0
Totals.....		8	4 (50%)	4 (50%)
34	187	1	1	0
	188	2	0	1
	189	2a	0	1
	190	2b	0	1
	191	2c	0	1
	192	2d	1	0
Totals.....		6	2 (33%)	4 (66%)

TABLE XI—(Continued)

SNAIL No. 9—(Continued)

No. of days tested	No. of trial for series	No. of trial for day	No. of correct choices	No. of incorrect choices
35	193	1	0	1
	194	1a	0	1
	195	1b	1	0
	196	2	0	1
	197	2a	0	1
	198	2b	1	0
Totals.....		6	2 (33%)	4 (66%)
36	199	1	0	1
	200	1a	0	1
	201	1b	0	1
	202	1c	0	1
	203	1d	1	0
Totals.....		5	1 (20%)	4 (80%)
37	204	1	0	1
	205	1a	0	1
	206	1b	0	1
	207	1c	0	1
	208	1d	0	1
	209	1e	0	1
	210	2	1	0
Totals.....		7	1 (14%)	6 (85%)
38	211	1	1	0
	212	2	0	1
	213	2a	0	1
	214	2b	0	1
	215	2c	1	0
Totals.....		5	2 (40%)	3 (60%)

SUMMARY—SNAIL No. 9

No. of days tested	No. of trials	Correct choices	Incorrect choices
1	3	1	2
2	1	0	1
3	3	3	0
4	5	1	4
*5	5	1	4
*6	4	1	3
7	7	3	4
8	6	3	3
9	7	4	3
10	2	2	0
11	5	0	5
12	8	3	5
13	3	3	0

* Indicates that an egg mass had been deposited by the snail during the 24 hours immediately preceding the tests on the day marked.

TABLE XI—(Continued)

SUMMARY—SNAIL NO. 9—(Continued)

No. of days tested	No. of trials	Correct choices	Incorrect choices
14	4	1	3
15	5	3	2
16	6	3	3
17	5	3	2
18	7	3	4
19	5	2	3
20	4	2	2
21	5	3	2
22	6	4	2
23	7	4	3
24	5	2	3
25	10	6	4
26	7	5	2
27	8	3	5
28	7	2	5
29	4	1	3
30	7	4	3
31	7	2	5
32	10	5	4
33	8	4	5
34	6	2	4
35	6	2	4
36	5	1	4
37	7	1	6
38	5	2	3

Total number of trials..... 215
 Total number of correct choices..... 95 approximately 44%
 Total number of incorrect choices..... 120 approximately 56%

SUMMARY—SNAIL NO. 10

No. of days tested	No. of trials	Correct choices	Incorrect choices
1	6	1	5
2	3	2	1
3	6	3	3
4	1	1	0
5	3	1	2
6	3	1	2
7	6	3	3
8	5	1	4
9	2	1	1
10	5	2	3
11	5	3	2
12	9	3	6
13	10	3	7
14	6	1	5
15	6	2	4
16	8	4	4

TABLE XI—(Continued)

SUMMARY—SNAIL NO. 10—(Continued)

No. of days tested	No. of trials	Correct choices	Incorrect choices
17	11	3	8
18	9	5	4
19	5	1	4
20	14	4	10
21	9	1	8
22	7	3	4
23	5	1	4
24	3	2	1
25	11	2	9
26	6	3	3
27	15	5	10
28	5	4	1
29	8	2	6
30	7	1	6
31	5	2	3
32	6	3	3
33	4	1	3

Total number of trials..... 214

Total number of correct trials..... 75 approximately 35%

Total number of incorrect trials..... 139 approximately 65%

SUMMARY—SNAIL NO. 11

No. of days tested	No. of trials	Correct choices	Incorrect choices
1	4	3	1
2	6	1	5
3	5	4	1
4	9	4	5
5	7	3	4
6	5	0	5
7	8	1	7
8	7	5	2
9	5	5	0
10	3	2	1
11	9	7	2
12	6	4	2
13	9	3	6
14	6	4	2
15	5	1	4
16	8	5	3
17	7	0	7
18	10	3	7
19	7	3	4
20	9	2	7
21	7	2	5
22	7	1	6
23	7	3	4
24	8	2	6
25	14	7	7

TABLE XI—(Continued)

SUMMARY—SNAIL NO. 11—(Continued)

Total number of trials.....	178
Total number of correct trials.....	75 approximately 42%
Total number of incorrect trials.....	103 approximately 58%

SUMMARY—SNAIL NO. 27

No. of days tested	No. of trials	Correct choices	Incorrect choices
1	4	2	2
2	3	1	2
3	5	1	4
4	6	1	5
5	5	1	4
6	4	0	4
7	4	2	2
8	7	0	7
9	5	4	1
10	6	2	4
11	5	3	2
12	3	1	2

Total number of trials.....	57
Total number of correct trials.....	18 approximately 32%
Total number of incorrect trials.....	39 approximately 68%

TABLE XI-A

SUMMARY OF ROUGH-SHOCK-SMOOTH TESTS

	Snail No. 9	Snail No. 10	Snail No. 11	Snail No. 27
Total number of trials.....	215	214	178	57
Per cent of incorrect choices.....	56	65	58	68

Table XI shows the trials of four snails on the rough-shock-smooth Y-shaped labyrinth. These cover periods of 38, 35, 25, and 12 days and involve 215, 214, 178, and 57 trials, or a total of 664 trials. Of these 401 or 60.3% give wrong choices. The curves (figs. 19-22, Plate VII) show great irregularity, especially in the first third of their courses. Nearly all the days on which the choices were either all right or all wrong fall in this part of the curves. After this the curves fluctuate less from the fifty per cent level, but rise slightly as they proceed. In this series the snails climb a labyrinth of cylindrical glass and are free to move on any side of it; there is no question of right or left. The choice is made between rough and smooth. No rough-smooth preference tests were made, but there is evident in this

series a possible tendency to prefer the rough side. The punishment had no apparent effect upon this tendency. It seemed as though this might be due to the fact that owing to the construction of the apparatus the punishment (shock) was delayed too long after the warning stimulus (roughness) had been received,

6. EXPERIMENTS WITH Y-SHAPED LABYRINTH: MECHANICAL STIMULATION AS WARNING SIGNAL

The results treated in Table XI and in the group of figures (19-22, Plate VII) show no indication of learning. It is believed that the large percentage of error might have been lowered in a greater number of tests, but this would probably not account for the type of curve obtained. It was then suggested by Dr. John F. Shepard that while the snails were unable to solve the labyrinth they might nevertheless be able to form a simple association under the conditions of the labyrinth experiments. They might show on the labyrinth a capacity equal to that developed under tests with simultaneous stimuli. A series of tests was therefore carried out, using the Y apparatus with the electric shock punishment but modified as follows: 1. In place of roughness on the shock side a mechanical warning stimulus was used which could be observed to affect the snail. 2. The wrong arm of the labyrinth was shortened so that the shock followed immediately on the warning stimulus. The time relation of the two stimuli was similar to that in Yerkes' experiments (1912), with earthworms and approached that of the method of simultaneous stimuli. The Y apparatus just described was used in a slightly modified form. All traces of the sand and metal were removed. The long arm of the Y was shortened to 3 cm. in order to bring the reward nearer the point of divergence of the paths, while the short arm was reduced to 1.5 cm. in length in order to bring the punishment nearer to the point of the path which necessitated choice on the part of the snail. The snail was placed at the base of the path in the usual way. If at the top of the stem the short arm was chosen, as soon as the turn was made the tentacles and head were stroked with a hair. This was fastened to the end of a small stick so that it could be handled by the operator. This tactile stimulus was immediately followed by the usual electric shock. The fact that the tentacles were withdrawn and that the animal recoiled

slightly when touched with the hair, showed conclusively that the tactile stimulus was effective. A series of check tests in which this stimulus alone was used showed that the irritation thus caused was not severe enough to make it serve as a punishment. Six snails were used and the usual method of recording and curve plotting was followed.

TABLE XII

Showing the number of correct-by-chance, correct-by-association, and incorrect trials in a series of tests in which an electric shock was used as punishment in connection with a mechanical warning stimulus. The Y apparatus was used with the arms shortened to 3 cm. and 1.5 cm. In case of error in choice the snail was stroked across the dorsal head region with a hair and then given an electric shock. The apparatus was cleaned between tests. Four individuals of *Physa gyrina* Say were used.

SNAIL No. 9					
No. of days tested	No. of trial for series	No. of trial for day	Choices correct by chance	Choices correct by association	Incorrect choices
1	1	1	0	0	1
	2	2	1	0	0
	3	3	0	0	1
	4	3a	0	0	1
	5	4	0	0	1
	6	5	0	0	1
	7	6	0	0	1
	8	7	1	0	0
	9	8	0	0	1
Totals.....		9	2 (22%)	0	7 (77%)
2	10	1	0	0	1
	11	2	0	1	0
	12	3	1	0	0
	13	4	0	1	0
	14	5	0	1	0
	15	6	1	0	0
Totals.....		6	2 (33%)	3 (50%)	1 (16%)
3	16	1	1	0	0
	17	2	1	0	0
	18	3	0	0	1
	19	3a	0	1	0
	20	4	0	0	1
	21	5	0	0	1
	22	5a	0	0	1
	23	6	1	0	0
Totals.....		8	3 (37%)	1 (12%)	4 (50%)
4	24	1	0	1	0
	25	2	1	0	0
	26	3	0	1	0
	27	4	1	0	0
	28	5	1	0	0
	29	6	1	0	0
	30	7	1	0	0
Totals.....		7	5 (71%)	2 (28%)	0

TABLE XII—(Continued)

SNAIL NO. 9—(Continued)

No. of days tested	No. of trial for series	No. of trial for day	Choices correct by chance	Choices correct by association	Incorrect choices
5	31	1	0	0	1
	32	2	0	0	1
	33	3	0	0	1
	34	4	1	0	0
	35	5	0	0	1
	36	6	1	0	0
	37	7	0	1	0
Totals.....		7	2 (28%)	1 (14%)	4 (57%)
6	38	1	0	1	0
	39	2	1	0	0
	40	3	1	0	0
	41	4	1	0	0
	42	5	0	0	1
	43	6	1	0	0
	44	7	1	0	0
	45	8	1	0	0
Totals.....		8	6 (75%)	1 (12%)	1 (12%)
7	46	1	0	0	1
	47	2	0	0	1
	48	3	1	0	0
	49	4	1	0	0
	50	5	1	0	0
	51	6	0	0	1
	52	7	1	0	0
	53	8	0	1	0
Totals.....		8	4 (50%)	1 (12%)	3 (37%)
8	54	1	1	0	0
	55	2	0	0	1
	56	3	1	0	0
	57	4	0	0	1
	58	4a	1	0	0
	59	5	1	0	0
	60	6	0	1	0
	61	7	0	1	0
	62	8	1	0	0
Totals.....		9	5 (55%)	2 (22%)	2 (22%)
9	63	1	0	0	1
	64	1a	1	0	0
	65	2	0	0	1
	66	2a	1	0	0
	67	3	0	0	1
	68	4	0	0	1
	69	4a	0	0	1
	70	4b	0	0	1
Totals.....		8	2 (25%)	0	6 (75%)

TABLE XII—(Continued)

SNAIL NO. 9—(Continued)					
No. of days tested	No. of trial for series	No. of trial for day	Choices correct by chance	Choices correct by association	Incorrect choices
10	71	1	0	0	1
	72	2	0	1	0
	73	3	0	0	1
	74	3a	0	1	0
	75	4	0	1	0
	76	5	0	1	0
	77	6	0	1	0
Totals.....		7	0	5 (71%)	2 (28%)
11	78	1	1	0	0
	79	2	1	0	0
	80	3	0	0	1
	81	4	0	0	1
	82	5	1	0	0
	83	6	0	0	1
	84	6a	0	0	1
Totals.....		7	3 (42%)	0	4 (57%)
12	85	1	1	0	0
	86	2	1	0	0
	87	3	1	0	0
	88	4	1	0	0
	89	5	0	1	0
	90	6	1	0	0
Totals.....		6	5 (83%)	1 (16%)	0
13	91	1	1	0	0
	92	2	0	0	1
	93	3	0	1	0
	94	4	1	0	0
	95	5	1	0	0
	96	6	1	0	0
Totals.....		6	4 (66%)	1 (16%)	1 (16%)
14	97	1	0	0	1
	98	2	1	0	0
	99	3	1	0	0
	100	4	0	1	0
	101	5	1	0	0
	102	6	0	1	0
Totals.....		6	3 (50%)	2 (33%)	1 (16%)
15	103	1	0	1	0
	104	2	1	0	0
	105	3	1	0	0
	106	4	1	0	0
	107	5	0	1	0
	108	6	0	1	0
	109	7	1	0	0
Totals.....		7	4 (57%)	3 (42%)	0

TABLE XII—(Continued)

SNAIL No. 9—(Continued)

No. of days tested	No. of trial for series	No. of trial for day	Choices correct by chance	Choices correct by association	Incorrect choices
16	110	1	0	1	0
	111	2	0	1	0
	112	3	1	0	0
	113	4	0	1	0
	114	5	1	0	0
	115	6	1	0	0
Totals.....		6	3 (50%)	3 (50%)	0
17	116	1	0	1	0
	117	2	1	0	0
	118	3	1	0	0
	119	4	0	1	0
	120	5	1	0	0
	121	6	1	0	0
	122	7	1	0	0
	123	8	1	0	0
Totals.....		8	6 (75%)	2 (25%)	0
18	124	1	1	0	0
	125	2	1	0	0
	126	3	0	1	0
	127	4	1	0	0
	128	5	1	0	0
	129	6	1	0	0
	130	7	1	0	0
Totals.....		7	6 (85%)	1 (14%)	0
19	131	1	0	1	0
	132	2	0	1	0
	133	3	1	0	0
	134	4	1	0	0
	135	5	1	0	0
	136	6	1	0	0
Totals.....		6	4 (66%)	2 (33%)	0
20	137	1	0	0	1
	138	1a	0	1	0
	139	2	1	0	0
	140	3	1	0	0
	141	4	0	1	0
Totals.....		5	2 (40%)	2 (40%)	1 (20%)
21	142	1	1	0	0
	143	2	1	0	0
	144	3	0	1	0
	145	4	1	0	0
	146	5	0	0	1
	147	5a	1	0	0
Totals.....		6	4 (66%)	1 (16%)	1 (16%)

TABLE XII—(Continued)

SUMMARY—SNAIL NO. 9—(Continued)

No. of days tested	No. of trials	Choices correct by chance	Choices correct by association	Incorrect choices
1	9	2	0	7
2	6	2	3	1
3	8	3	1	4
4	7	5	2	0
5	7	2	1	4
6	8	6	1	1
7	8	4	1	3
8	9	5	2	2
9	8	2	0	6
10	7	0	5	2
11	7	3	0	4
12	6	5	1	0
13	6	4	1	1
14	6	3	2	1
15	7	4	3	0
16	6	3	3	0
17	8	6	2	0
18	7	6	1	0
19	6	4	2	0
20	5	2	2	1
21	6	4	1	1

Total number of trials..... 147
 Total number correct by chance..... 75 approximately 51%
 Total number correct by association..... 34 approximately 23%
 Total number incorrect..... 38 approximately 26%

SUMMARY—SNAIL NO. 10

No. of days tested	No. of trials	Choices correct by chance	Choices correct by association	Incorrect choices
1	7	3	0	4
2	5	5	0	0
3	11	7	0	4
4	10	4	0	6
5	7	3	0	4
6	6	3	0	3
7	8	5	0	3
8	5	3	0	2
9	9	4	2	3
10	10	2	1	7
11	7	4	1	2
12	7	5	1	1
13	6	2	1	3
14	9	4	1	4
15	9	4	2	3
16	8	4	0	4
17	7	5	1	1
18	10	2	0	8

TABLE XII—(Continued)

SUMMARY—SNAIL NO. 10—(Continued)

No. of days tested	No. of trial for series	No. of trial for day	No. of correct choices	No. of incorrect choices
19	7	5	2	0
20	6	2	4	0
21	6	1	4	1
22	7	3	1	3
23	6	4	1	1

Total number of trials..... 173
 Total number correct by chance..... 84 approximately 48%
 Total number correct by association..... 22 approximately 13%
 Total number incorrect..... 67 approximately 39%

SUMMARY—SNAIL NO. 13

No. of days tested	No. of trials	Choices correct by chance	Choices correct by association	Incorrect choices
1	5	0	0	5
2	5	3	0	2
3	10	6	0	4
4	5	3	0	2
5	6	3	0	3
6	5	4	0	1
7	10	5	1	4
8	5	4	0	1
9	10	5	1	4
10	7	2	1	4
11	7	3	1	3
12	8	4	0	4
13	8	6	0	2
14	9	5	2	2
15	8	3	4	1
16	6	3	2	1
17	7	3	2	2

Total number of trials..... 121
 Total number correct by chance..... 62 approximately 51%
 Total number correct by association..... 14 approximately 12%
 Total number correct by chance..... 45 approximately 37%

SUMMARY—SNAIL NO. 19

No. of days tested	No. of trials	Choices correct by chance	Choices correct by association	Incorrect choices
1	9	2	0	7
2	8	6	2	0
3	8	4	3	1
4	6	1	3	2
5	6	3	1	2

TABLE XII—(Continued)

SUMMARY—SNAIL NO. 19—(Continued)

No. of days tested	No. of trials	Choices correct by chance	Choices correct by association	Incorrect choices
6	5	4	1	0
7	6	2	2	2
8	5	4	1	0
9	7	5	1	1
10	8	3	3	2
11	7	5	1	1
12	7	6	0	1
13	8	4	1	3
14	8	4	3	1
15	6	3	2	1
16	6	5	1	0
17	6	4	2	0
18	6	4	2	0
19	6	2	2	2
20	6	4	1	1
21	7	3	2	2

Total number of trials..... 141
 Total number correct by chance..... 78 approximately 55%
 Total number correct by association..... 34 approximately 24%
 Total number incorrect..... 29 approximately 21%

SUMMARY—SNAIL NO. 21

No. of days tested	No. of trials	Choices correct by chance	Choices correct by association	Incorrect choices
1	6	5	0	1
2	8	6	0	2
3	8	3	0	5
4	7	2	1	4
5	6	2	0	4
6	8	2	2	4
7	7	5	0	2
8	8	6	1	1
9	8	8	0	0
10	5	1	0	4
11	4	3	0	1
12	5	3	2	0
13	6	3	2	1
14	5	5	0	0
15	6	3	2	1
16	7	6	0	1
17	7	4	0	3
18	7	6	0	1
19	6	3	1	2
20	6	4	0	2
21	5	4	1	0
22	6	4	1	1
23	8	4	0	4

TABLE XII—(Continued)

SUMMARY—SNAIL No. 21—(Continued)

No. of days tested	No. of trials	Choices correct by chance	Choices correct by association	Incorrect choices
24	6	2	2	2
25	5	2	2	1
26	8	4	1	3
27	6	3	2	1

Total number of trials..... 174
 Total number correct by chance..... 103 approximately 59%
 Total number correct by association..... 20 approximately 12%
 Total number incorrect..... 51 approximately 29%

SUMMARY—SNAIL No. 22

No. of days tested	No. of trials	Choices correct by chance	Choices correct by association	Incorrect choices
1	6	1	0	5
2	8	2	1	5
3	7	4	0	3
4	6	3	1	2
5	8	1	0	7
6	8	5	1	2
7	8	3	1	4
8	12	1	1	10
9	7	2	1	4
10	5	0	0	5
11	5	4	0	1
12	6	4	0	2
13	7	4	0	3
14	5	2	0	3
15	9	3	2	4
16	7	4	0	3
17	9	4	1	4
18	6	5	0	1
19	7	4	1	2
20	7	2	0	5
21	5	2	1	2
22	5	1	4	0
23	7	3	2	2
24	6	3	2	1
25	6	4	1	1
26	6	4	1	1
27	6	4	1	1

Total number of trials..... 174
 Total number correct by chance..... 79 approximately 45%
 Total number correct by association..... 22 approximately 13%
 Total number incorrect..... 73 approximately 42%

TABLE XII-A

Summary of tests in which a mechanical stimulus was used in connection with electric shock.

	Snail No. 9	Snail No. 10	Snail No. 13	Snail No. 19	Snail No. 21	Snail No. 22
Total number of trials.....	147	173	121	141	174	174
Per cent of choices correct by chance.....	51	48	51	55	59	45
Per cent of choices correct by association.....	23	13	12	24	12	13
Per cent of incorrect choices..	26	39	37	21	29	42

Table XII shows that in a total of 930 trials on six individuals of *Physa*, 51.2% were correct by chance, that is, the correct path was chosen without contact with the warning stimulus. In 15.6% of the trials the correct path was chosen after contact with the warning stimulus, but without punishment, showing that a weak association had been formed between the two stimuli. In 32.5% of the trials, the warning stimulus was disregarded and punishment received. This shows that the behavior of the snails tested was modified during the experiments inasmuch as they apparently learned to recognize the warning stimulus and turned back before receiving the electric shock. The snails profited by experience. The slightly downward tendency of the jagged curves based on these records (figs. 23-28, Plate VIII) shows an erratic decrease in error, weak association and limited associative memory.

7. SUMMARY OF OBSERVATIONS

1. All observations and experiments were made on the snail *Physa gyrina* Say while in tap water at room temperature and under uniform lighting conditions.

2. When the air is pressed from the lung of *Physa* and the snail is placed in the water at the base of a U-shaped labyrinth supported on an upright stem, it crawls up the stem and along the arms of the U to the surface of the water. Fig. 14, Plate IV.

3. *Experiments to test right or left preference: first series.*—In a series of 24 trials in which three individuals of *Physa* were deprived of air and placed on the bottom near the wall of a glass dish filled with water, and allowed to crawl unhindered to the surface of the water, the path chosen deviated from a

perpendicular toward the right in 54.1% of the trials and toward the left in 45.8% of the trials. This showed that the natural path chosen by the three snails tested, in traveling over a flat unrestricted substratum to the surface of the water for air, in a comparatively small number of trials deviated somewhat to the right. Table VII, p. 43.

4. *Experiments to test right and left preference: second series.* When the U apparatus (paragraph 1) is bordered by a "picket fence" of wires, the snail is forced to travel on one side. When it reaches the top of the stem it must turn toward either the right or left end of the horizontal bar of the U to reach the surface of the water. Fig. 14, Plate IV.

5. In a series of 240 trials in which the two arms of the U were identical and both reached the surface of the water, the three snails tested followed the right arm in 51.6% of the trials and the left arm in 48.3%, showing a slight right preference for the snails tested. Table VIII, p. 45.

6. *Experiments to test preference for an ascending or descending path.*—In order to determine whether any preference existed for an ascending or a descending path, the U-shaped labyrinth was so tilted that the bar of the U deviated from a horizontal at angles varying from 0–1 degree to 7–8 degrees. In 600 trials the three snails tested chose the descending arm in 43% of the trials and the ascending arm in 57%, showing a slight preference for an ascending path. Table IX, p. 47.

7. In subsequent experiments in which the U labyrinth was used the horizontal bar was kept level.

8. In the experiments to test learning, complete records are presented for two individuals in each series of tests and summaries of results are given for additional snails tested.

9. *Experiments on learning the U-shaped labyrinth.*—In a series of 888 tests on three individuals of *Physa*, using the U-shaped labyrinth with the right arm shortened so that a snail could not reach the surface of the water from its upper end, thus making failure to obtain air serve as a punishment incident to the choice of this arm, 58.8% of the turns were toward the right, that is, incorrect, and 41.2% toward the left or correct. There is then shown no evidence of ability in the snail to distinguish right or left in connection with failure to

obtain air (punishment) and the attainment of air (reward). Table X, p. 48.

10. The curves based on these trials show irregularity at the beginning and a slightly upward tendency toward the end, indicating that the possible right preference was covered in the early part of the series by disturbance such as manipulation and the change in apparatus. Figs. 16-18, Plate VI.

11. *Experiments with Y-shaped labyrinth: roughness of the path as a warning stimulus; electric shock as punishment.*—In a series of 664 tests a Y-shaped path of glass tubing, unlimited by wires, was used. One arm of the Y gave access to the surface of the water and the other was shortened and supplied with wires over which an electric current could be sent. The space between the point of divergence of the two arms and the wires was roughened. The four snails tested chose the short arm or punishment in 60.3% of the trials. This series of tests then, shows no indication of learning. Table XI, p. 63.

12. The curves based on these trials show less irregularity than those in the preceding tests (paragraph 10). The latter part lies slightly above the 50% level indicating a possible preference for the rough side, masked by disturbance in the first part of the series, combined with punishment too long delayed after the warning stimulus had been received. Figs. 19-22, Plate VII.

13. *Experiments with Y-shaped labyrinth: mechanical stimulation as warning signal.*—In a series of 930 tests the Y apparatus was used but instead of roughness in connection with the electric shock, the snail was stroked on the tentacles and dorsal head region with a hair, preceding the shock, if a wrong choice were made. Check tests showed that the irritation caused by the warning stimulus was not sufficient to cause it to serve as a punishment. The six snails tested chose the short arm and punishment in 32.5% of the trials, the long arm, by chance in 51.2% and the long arm through association in 15.6%. Modification of behavior through the formation of an association between the two stimuli, one serving as punishment, the other as a warning signal, is thus shown. Table XII, p. 73.

14. The curves based on these trials show irregularity throughout but a downward tendency toward the latter end, indicating

the formation of a weak association between the two stimuli used. Figs. 23-28, Plate VIII.

15. The last series of experiments (paragraph 13) shows results comparable to those obtained in the first part of the present work which indicated an association formed between two dissimilar stimuli, food and pressure, in a series of tests based on the Pawlow salivary method. It does not show ability to learn the labyrinth.

8. DISCUSSION

The foregoing attempt to learn whether the snail can solve a simple vertical U- or Y-shaped labyrinth falls into three series.

1. In the *first* of these there was used a U-shaped labyrinth supported on a stem and bordered by a paling of wires so that the snails could crawl up but one side of it. At the top of the stem they had a choice of a right or left path. If the right path were chosen it led to the right vertical bar of the U from the top of which the snail could not reach the surface of the water. If the left path were chosen it led to the vertical bar of the U, longer than the right, from the top of which the snail could fill its lung with air. The upward course of the snail is in search of air. Choice of the right path resulted in failure to get air which was assumed to act as punishment. Such a choice was regarded as incorrect. Choice of the left path led to the attainment of air, which was regarded as reward and such choice was registered as correct.

Preliminary tests showed that the snails have a slight preference for the right path, a preference possibly related to the asymmetry of the animal. It was to be expected that this right preference would appear at the beginning of the series of learning tests, but that it would be soon corrected by the result of the learning process. If the snails actually learned and a curve were plotted showing their percentage of errors from each successive day's experience, this curve would start somewhere above the 50% level on account of the right preference, which would result in an excess of incorrect choices. The curve would then gradually descend, through learning, toward the zero level with decrease in error present. If the snail did not learn and were in no way affected by its experiences with the labyrinth the curve of errors might be expected to follow the 50% level or somewhat above it, while fluctuating above and below.

An inspection of the graphs (Plate VI) shows that the curves are quite irregular and with the progress of time there is a slight tendency to rise above the 50% level. The snails not only do not learn but their percentage of errors apparently increases as the series of trials lengthens. Nothing has been detected in the physical environment to direct the snail to either side of the path. It is in a symmetrical environment as to structure of labyrinth, surrounding tank and house, lighting and temperature. It seems probable that the disturbance due to manipulation and the change in conditions incident to the experimental work probably caused irregularities in the first part of the series which covered the slight tendency to turn to the error (right) side of the path, evident in the latter part of the curves. The graphs show then, a probable masking of the "right" preference in the early part of the experiments, due to disturbance rather than increase in this preference as the series lengthens. *There is no evidence of learning.*

2. In the *second series* of labyrinth tests the U-shaped labyrinth was discarded and in its place was used a Y-shaped labyrinth of cylindrical glass tubing. Owing to the snail's tendency to crawl in a spiral such a labyrinth offers no choices of right or left and the snail is free to move in any direction in order to reach the top. One arm of this labyrinth was made rough while the other remained smooth. Thus roughness served as a means of discrimination between the two. At the upper end of the rough arm the snail received an electric shock. The roughness served as a warning signal of the approaching shock. No rough-smooth preference tests were made.

The curves (Plate VII) again show much irregularity, but not so much as those with the U-shaped labyrinth. There are again days on which all choices are correct and other days on which all are incorrect. Nearly all of these days, however, fall in the first third of the curves, with the result that this part is much more irregular than that which follows. After their first thirds the curves remain nearer the 50% level, but on the whole tend to lie above it. In other words, the percentage of error again appears to increase as the series lengthens. It seems possible that a greater number of trials might have brought the curves again to the 50% line or even slightly below it, indicating that the upward tendency was due to a wave of error and that a

corresponding wave showing fewer errors might follow. It is more probable however, that the greater irregularity evident in the first thirds of the curves was due in part to disturbance following the change of apparatus and that the slight increase in error toward the end was the result of a possible rough preference linked with a too long delayed punishment.

3. The *third series* of labyrinth tests was planned to test the capacity of the snail to form associations on the labyrinth that it had failed to solve. The Y labyrinth was used, but all traces of roughness were removed. The short arm was shortened still more making the interval between the warning stimulus and the punishment less than in the preceding tests. The warning stimulus adopted was the irritation caused by stroking the dorsal head region and tentacles of the snail with a hair. That this stimulus was an irritation was evidenced by the fact that its use caused the snail to withdraw its tentacles, and at times to partially retract its head toward the edge of its shell. Check tests, however, showed that the irritation was not severe enough in itself to act as a punishment. The labyrinth as before offered no choice of right or left.

The curves (Plate VIII) of error percentage show much irregularity but a slight downward tendency. In 15.6% of the total of 930 trials, the snails changed their course from the wrong to the right path after contact with the warning stimulus but before the shock (punishment) was received. Since the warning stimulus was known to irritate the animal, there could have been no preference for the wrong side of the labyrinth to offset the associative effect of the shock (punishment). The 15% of correct-by-association trials, then, represents the strength of the association formed between the warning stimulus and the punishment, no part of which could have been masked through preference for the signal stimulus used. This series of tests thus shows the formation of a weak association between two stimuli, one used as a warning of the punishment to follow if the course be not changed. *Physa* then, profits by experience, but cannot be said to solve a labyrinth. The work with the modified apparatus is merely confirmatory of that by the method of simultaneous stimuli. It shows no greater capacity on the part of the snail than was made evident by that method except that to form an association between stimuli separated by a small time interval.

Observational work on mollusks has been reported, but little experimental work has been done on this group of animals, none along the lines of the present work. Kollmann (1877) attributed "consciousness" to *Octopus vulgaris*, basing his conclusions, however, on observation rather than experiment. In his analysis of this report, Schneider (1909) explains the behavior observed as reflexive, not "conscious," and hence typical of any of the lower animals.* Piéron (1909) concludes that the octopus is capable of "learning," and although Kafka (1914) reports this work he does not analyze it. Modifiability of behavior then, may be attributed to members of the Cephalopod group. Piéron (1909), (1911) experimented on the waning of the effect of stimuli inducing reflexive action in *Limnaea stagnalis* and *Littorina*, which he terms memory. Associative memory as observed in the present work was believed to be an added proof of learning, but no attempt was made to determine its exact duration nor the way in which it developed. The work of Piéron is here of interest only in that it deals with so-called memory (adaptation) in closely related forms.

III. CONCLUSIONS

1. The present work on the snail, *Physa gyrina* Say, gives much evidence of capacity for adaptation—the getting-used-to-the-stimulus. This is quite apart from evidence for fatigue which appears in some places.

2. In addition to adaptation its behavior is modifiable by experience in another way. As the result of prolonged training with two simultaneous stimuli it is found to have acquired a response to one of these stimuli which it did not give before. It has formed an association between the two stimuli.

3. This definite acquired response is retained for four days beyond the completion of the training (memory).

4. When put through a long series of tests with the simplest form of labyrinth, under controlled conditions it shows no capacity to solve the labyrinth.

5. On a similar labyrinth it gives evidence of the capacity to form associations.

6. The capacity to form associations does not then suffice for the solution of the simplest labyrinth, that is, "selective" ability is apparently lacking.

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PLATE I

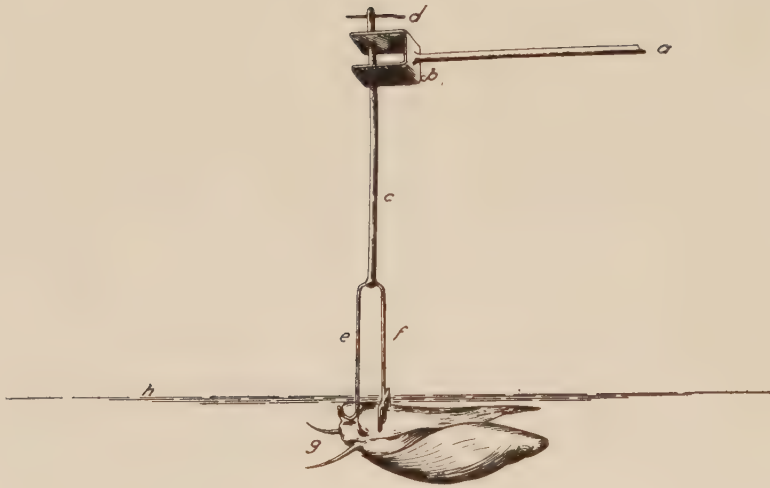
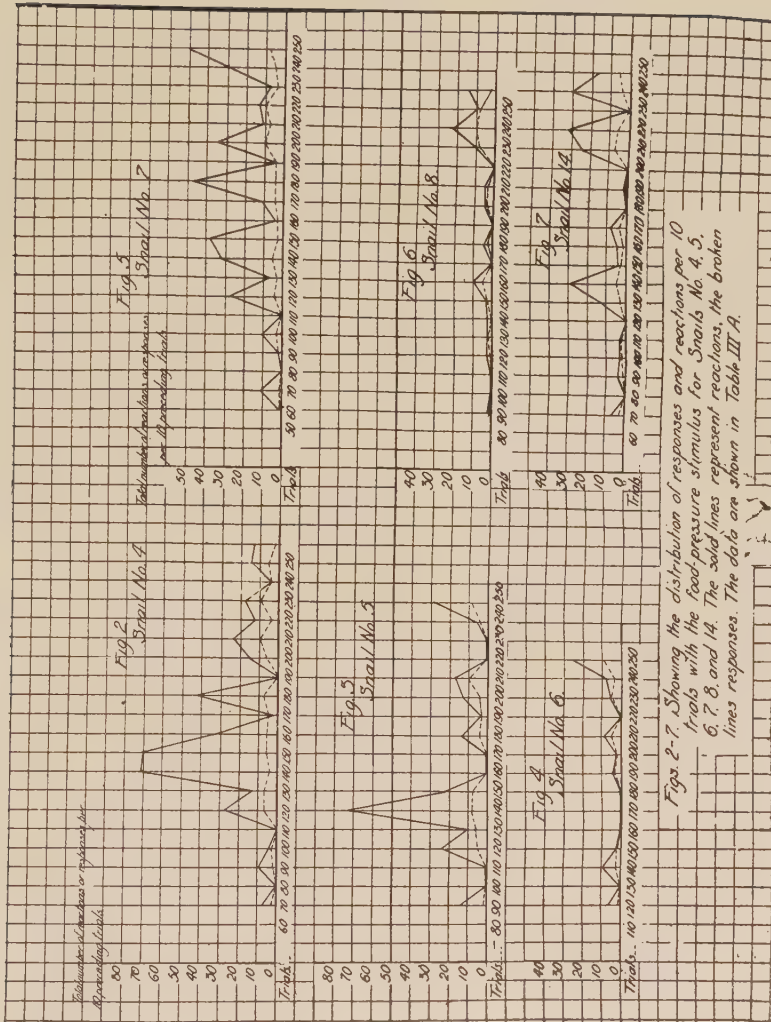
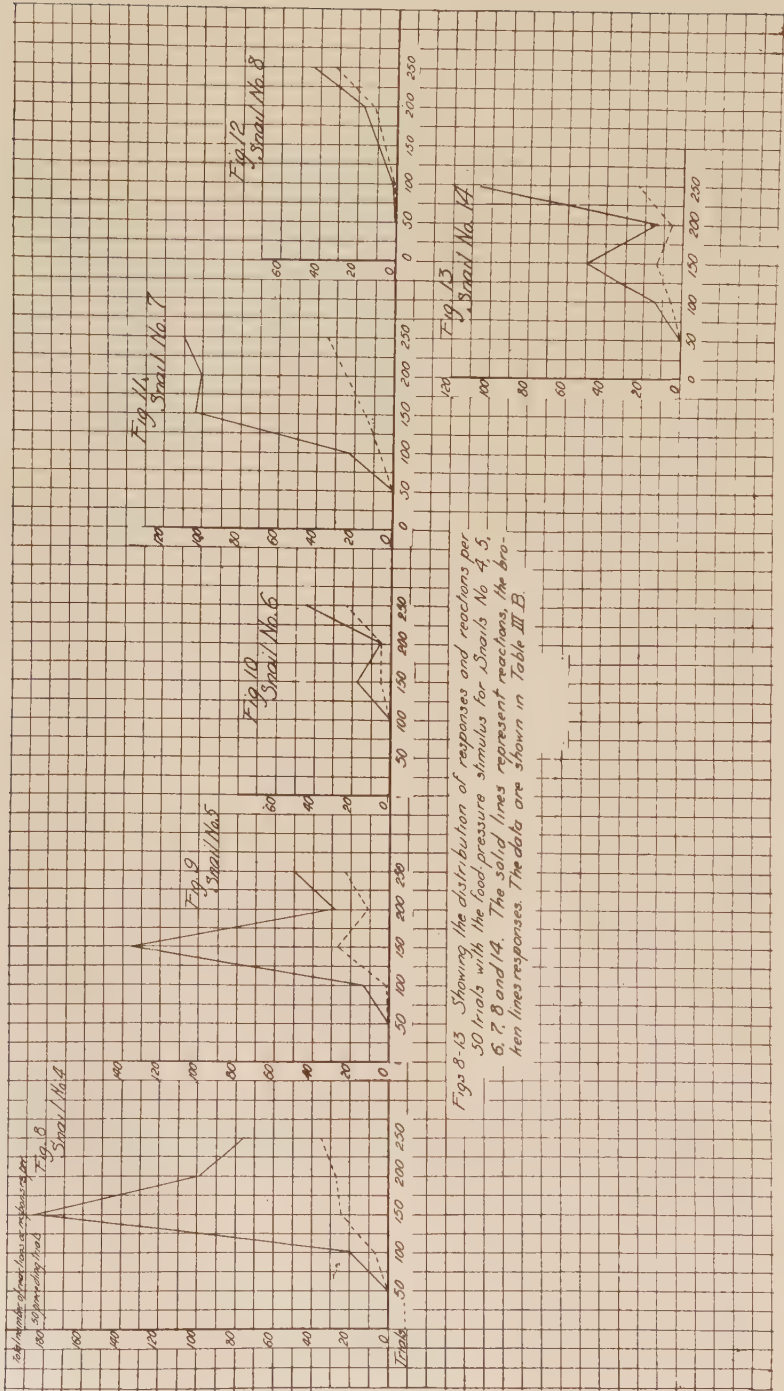


Fig. 1.

Apparatus used in experiments which required the simultaneous application to the snail of food and pressure and pressure alone. a, handle; b, sheet of metal; c, steel needle; d, wire through eye of needle; e, food hook; f, pressure fork; g, snail; h, surface of water.

PLATE II





Figs. 8-13 Showing the distribution of responses and reactions per 50 trials with the food-pressure stimulus for Snails No. 4, 5, 6, 7, 8 and 14. The solid lines represent reactions, the broken lines responses. The data are shown in Table III B.

PLATE IV

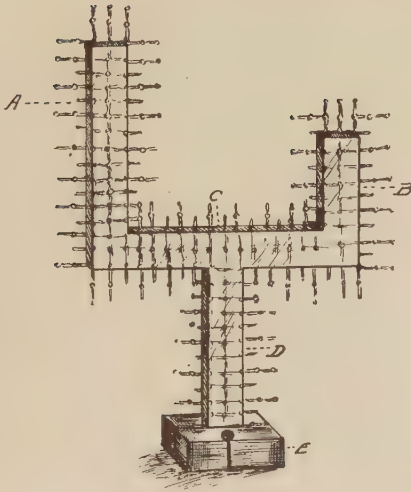


Fig. 14. - U shaped labyrinth with its picket fence of wires. A, long arm of the U giving access to the surface of the water; B, short arm of the U from the upper end of which air could not be obtained; C, horizontal bar of the U; D, upright stem upon which the U rested; E, lead base which anchored the labyrinth to the bottom of the tank.

PLATE V



Fig.15.

Showing the apparatus used in an attempt to control light conditions, experimental tank, Y shaped labyrinth used in later experiments, and rheostat used in controlling the electric current used in administering the shock.

PLATE VI

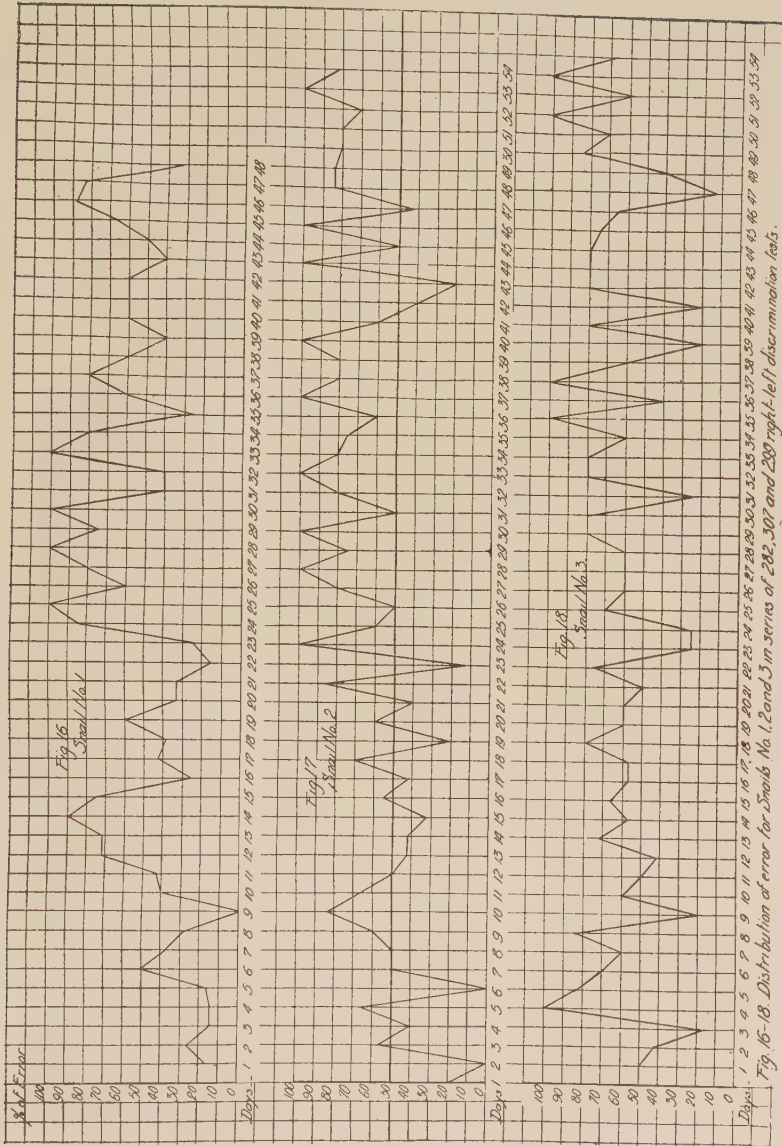


Fig. 16-18. Distribution of error for Shields No. 1, 2 and 3 in series of 288, 307 and 289 right-left discrimination tests.

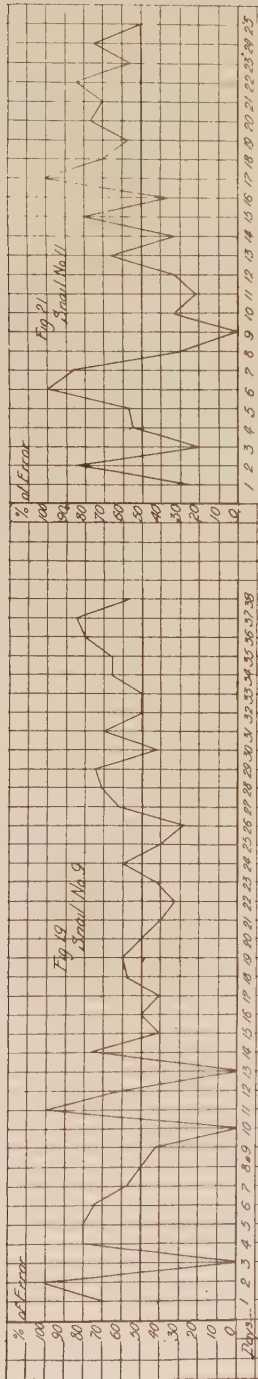


Fig. 19. Showing the distribution of error in the rough shock-smooth tests for Snail No. 9. in a total of 38 trials, extending over a period of 38 days.

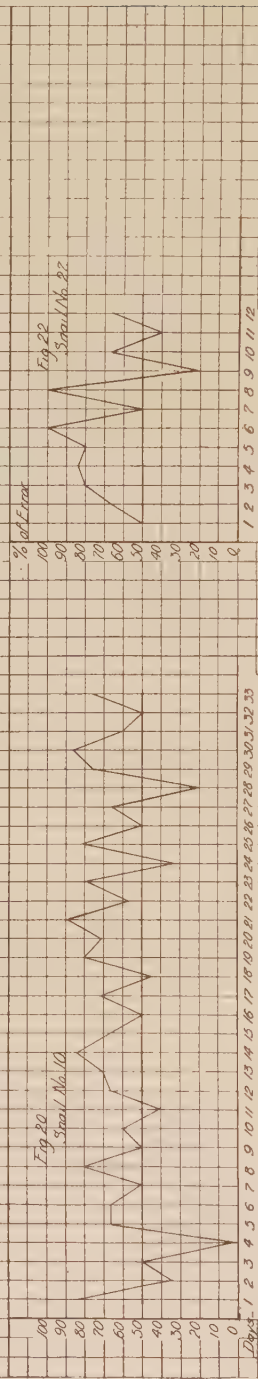


Fig. 20. Showing the distribution of error in the rough shock-smooth tests for Snail No. 10 in a total of 33 trials, extending over a period of 33 days.

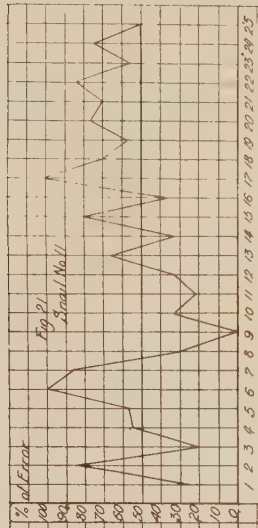


Fig. 21. Showing the distribution of error in the rough shock-smooth tests for Snail No. 11, in a total of 25 trials, extending over a period of 25 days.

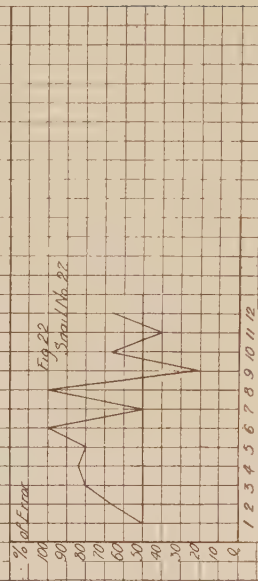
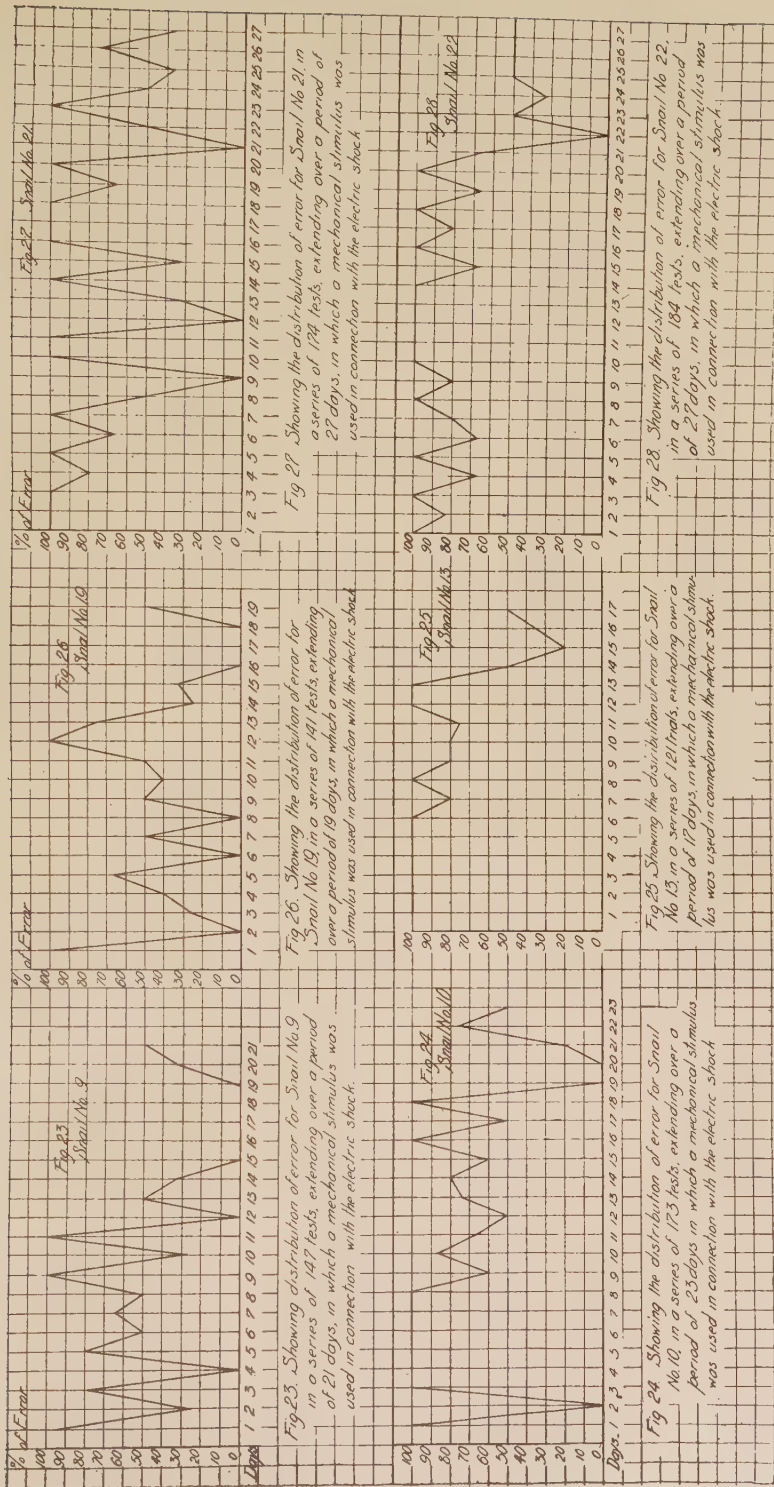


Fig. 22. Showing the distribution of error in the rough shock-smooth tests for Snail No. 22 in a total of 12 trials, extending over a period of 12 days.



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